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Game Playing Machines
C. E. Shannon

Recent Developments in the Technology of Ceramic Materials for Nuclear Energy Service
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Analysis of a Differential Magnetic Amplifier with Flux Reset Control
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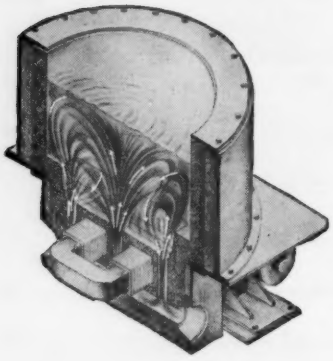

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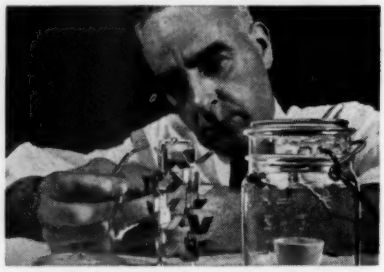

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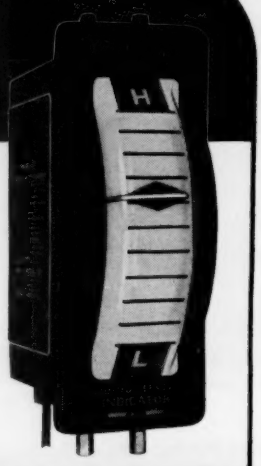

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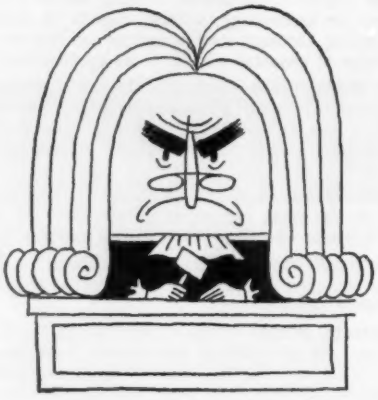

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GAME PLAYING MACHINES *

BY

C. E. SHANNON [1]

The design of game playing machines may seem at first an entertaining pastime rather than a serious scientific study and, indeed, many scientists, both amateur and professional, have made a hobby of this fascinating subject. There is, however, a serious side and significant purpose to such work, and at least four or five universities and research laboratories have instituted projects along this line. If Benjamin Franklin were alive today, I am sure he would be interested in this problem for it combines two of his avocations. We are all familiar with his achievements as a scientist and an inventor; it is not so well known that he was also a strong chessplayer. Indeed, he is the author of an engaging essay called "The Morals of Chess"—a blend of diplomacy and chess that might well have been subtitled "How to be Happy Even Though a Chessplayer."

One of the most important technological advances of the last twenty years has been the development of large scale electronic computing machines. These computers are capable of carrying out automatically and at the speed of thousands of operations per second a long sequence of numerical operations. The series of instructions which tells the computer exactly what it should do is called the program. When a computer is to solve a problem, a program must first be devised which translates the solution into a series of simple operations. These basic orders might consist of the elementary operations of arithmetic, addition, multiplication and the like, and also "decision" orders which enable the machine to make a choice between two alternatives, the choice depending upon the results of previous calculations. When the

* Delivered at the 1955 Medal Day Meeting, October 19, 1955, in acceptance of the Stuart Ballantine Medal.

[1] Bell Telephone Laboratories, Murray Hill, N. J.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

program is introduced into the machine, it carries out the instructions one by one at high speed.

Electronic computers are normally used for the solution of *numerical* problems arising in science or industry. The fundamental design of these computers, however, is so flexible and so universal in conception that they may be programmed to perform many operations which do not involve numbers at all—operations such as the translation of language, the analysis of a logical situation or the playing of games. The same orders which are used in constructing a numerical program may be used to symbolize operations on abstract entities such as the words of a language or the positions in a chess game.

Programming computers to perform such non-numerical tasks is valuable in a number of ways. It widens our understanding of the capabilities of this amazingly flexible tool, the general purpose computer; it seems certain that we have only scratched the surface of the potentialities of such computing devices and each new application leads to new understanding. Also, this wider use of the computers suggests useful changes in their design; new types of orders which will enhance their value in these more unusual programs and even in the ordinary numerical problems. Finally, we hope that research in the design of game playing machines will lead to insights in the manner of operation of the human brain. It would, of course, be naive to expect that the brain operates in a manner similar or even vaguely analogous to that of a machine designed to play a game. It is nevertheless certain that the design of any learning machine will illuminate the path toward the understanding of brain functioning.

Perhaps the earliest game playing machine was the chessplaying Automaton of Maelzel. This was a device constructed in 1769 by the Austrian inventor von Kempelen and exhibited widely in Europe and America by the promoter Maelzel. A large mechanical figure seated at a desk would play chess against human opponents. Before the performance the desk and figure were opened to show that there was no one inside. In its games, the machine usually won. The automaton created quite a sensation at the time and a number of theories were proposed to explain its operation. Among these, for example, was an essay by Edgar Allen Poe who concluded correctly (although in part by fallacious arguments) that the machine was a hoax and in fact was operated by a human chessmaster cleverly concealed inside. This was indeed the case, the effect being produced as in many cases of magical tricks by moving the chessmaster about within the machine as the various compartments and doors were opened for inspection. After many adventures, including some games with the Emperor Napoleon, the automaton ended up in a place called the Chinese museum here in Philadelphia and was finally destroyed by fire in 1854.

A modern counterpart to the Maelzel Automaton came to my

attention a few years ago. A friend in California wrote me that a checker playing machine had been exhibited there both in local department stores and on television. Almost invincible, it had even played the United States checker champion a drawn match and was widely accepted as an authentic electronic computer. Having investigated the problem of programming machines for chess and checkers, I was rather skeptical, particularly in view of the reported strength of play and portability, and suggested an investigation of the device. After considerable detective work, my friend finally tracked down the checker player in an old warehouse. He reported that the only electronic component was an electric fan to keep the concealed human operator cool!

Apart from such hoaxes, game playing machines may be divided into three main types depending on their level of sophistication. The simplest type of machine is that designed for games which have been completely analyzed. By this we mean that a complete strategy of play of relatively simple nature is known, a strategy of play which dictates an appropriate move for each situation in the game. This is the case, for example, in tic-tac-toe, in the match game of Nim and in a number of other mathematical games. In cases such as these, one can translate the known strategy into a program for a general purpose computer or into a special purpose computer so that the machine will make the correct move for each situation in the game. This type of machine will typically play a perfect game. It will win whenever it is possible to win.

One of the first machines of this type was developed about 1914 by a Spanish inventor Torres y Quevedo. It was a machine which played the end game in chess of king and rook against king. This end game is a relatively easy one and the proper moves can be described with only a few simple rules. The Torres machine translated these rules into a switching circuit—while by today's standards the device seems simple, it was certainly a remarkable invention for that period.

Another game susceptible of complete mathematical analysis is the game of Nim and many Nim-playing machines have been constructed. The first, I believe, was one exhibited at the World's Fair in New York in 1939. The game of Nim was analyzed early by mathematicians, who found that the correct strategy of play could be stated quite simply in terms of the binary notation for numbers. Relay circuits are most naturally adapted to the binary notation and consequently it was an easy step to translate the mathematical strategy for Nim into a relay circuit. Most of the Nim machines which have been built play a perfect game in the sense of winning whenever it is possible, but they usually give the human opponent a starting position that he can win if he plays without error. If he makes a single error the machine seizes the initiative and will win the game.[2]

[2] Here the speaker demonstrated a small Nim playing machine.

The familiar game of tic-tac-toe is a favorite among amateurs and hobbyists for machine construction. The game can be completely analyzed by enumeration of all possible lines of play. When the symmetry of the board is taken into account the number of such variations is relatively small. One of the earliest tic-tac-toe machines was designed by W. Keister about fifteen years ago and I have here a tic-tac-toe machine using Keister's circuit. In this machine the human player has first move and the machine will always at least draw the game. If the player makes a serious mistake, however, the machine will win. It also has "anti-cheat" features built in. If one attempts to make two moves at once, a "tilt" light goes on.[3]

The second main class of game playing machines relates to games for which a complete analysis is unknown but for which certain general principles of play or maxims of sound strategy are available. This includes most of the games of every day interest such as checkers, chess, bridge, or poker. A machine for playing chess by such general principles would investigate, in a given position, the different moves it could make, the different replies available to its opponent, and so on for two or three moves. At the end of each of these variations it might apply an "evaluation function" to the resulting positions. It would choose as its move that one which leads to the position of highest value, when its opponent is assumed to play in such a way as to minimize this value. This is a kind of *minimax* procedure familiar in the theory of games. Insofar as the evaluation function or the general principles of play are not infallible, a machine designed along these lines would not play a perfect game. It might be expected, however, to make tolerably good moves if the general principles were carefully thought out.

One example of a machine playing by general strategic principles of the type just mentioned is the checker playing routine devised by C. S. Strachey for use on a large scale computing machine. The first game played by Strachey's routine gave the indication of reasonably good play in the opening and middle game but very poor play in the end game. It is evident that a rather different type of program should be used in the later stages of play.

Another checker playing routine has been devised by A. L. Samuel and it is rumored that a match is being arranged between the two machines. There is a possibly apocryphal story with regard to Dr. Samuel's program. When he first introduced it into a computing machine and pressed the start button for the machine to give its first move the computer operated furiously for a few minutes and then printed out "I resign!".

Another quite different general principle type game player was designed by E. F. Moore and myself. It is a special purpose machine

[3] Here the lecturer demonstrated the operation of the tic-tac-toe machine.

designed to play a game of Hex. Hex is a game played on a board laid out in a regular hexagon pattern. Two players alternate in playing men on the hexagons. One player uses yellow men and the other uses blue men. The object of the yellow player is to form a connected path of yellow men from the top of the board to the bottom. The object of the blue player is to form a connected path of blue men between the two sides of the board. After some study of this game Moore and I conceived the idea of representing the board by a resistance network and the placement of men by voltages applied to corresponding points of the network; + voltage for the yellow men and − voltage for the blue men. We suspected that certain saddle points in the potential field produced in this resistance network would correspond to good moves in the game. A simple device was built embodying this network and it turned out that the machine played a tolerably good game. It would win when it had first move perhaps 70 per cent of the time against laboratory visitors. With second move its score was perhaps 50 per cent or less. We were often agreeably surprised to find the machine selecting moves which at first looked weak but careful analysis proved sound and strong. Indeed in one early position of the game the machine "discovered" a move which is better than any we had used in that position and which we now normally adopt.

The third and most sophisticated type of game playing machine is one which learns its own principles of play. Only the rules of the game and the desired goal are introduced into the program, together with some general principles of how to improve the play through experience. The machine is then allowed to play many games and by trial and error, by imitation of its opponent, by analysis of its failures or by other means it is supposed to gradually improve its playing skill. Although this problem has been discussed a good deal, no machines quite coming up to these specifications have been actually designed. The problem is one of great difficulty and the cost of carrying out such a research program would be great. However, at a somewhat more elementary level, learning machines have been built. Two examples of these will be described.

D. W. Hagelbarger has developed an interesting device which plays the game of matching pennies against a human opponent. In the ordinary game of matching pennies two players expose coins at the same time. They may arrange to have either the heads or the tails facing up when the coin is exposed. If the two coins are the same, one player wins. If they are different the second player wins. In actual play this results in a kind of psychological outguessing game. The player who can predict his opponent's reactions better will in the long run win. Hagelbarger's machine plays this game substituting lights and switches for the coins. The machine has memory registers in which are stored some of the results of the play against its opponent.

As it plays against the opponent these results are analyzed in the machine in an attempt to find certain patterns or psychological tendencies on the part of the human player. For example, one individual might have a tendency if he had won twice in a row to change from heads to tails. Another individual might have just the opposite tendency. The outguessing machine searches for such tendencies and those that it finds it exploits in future play. Thus, it assumes that in the future the human player will follow the tendencies he has exhibited in the past and the machine plays in such a way as to win if he in fact does so. In actual play the penny matcher has won something like 55 per cent of the time against a wide variety of opponents, definitely better than the 50 per cent it would win by pure chance.

Fascinated by Hagelbarger's machine, I designed a second penny matcher along the same general lines but simplified a great deal with regard to memory capacity and other details. After considerable discussion concerning which of these two machines would win over the other we decided to put the matter to an experimental test. A third small umpire machine was constructed which was able to pass information back and forth between the two machines, keep score, and ensure that the Queensbury rules were followed. The three machines were plugged together and allowed to run for a few hours to the accompaniment of small side bets and large cheering. It turned out that the smaller, presumably less "intelligent" of the two machines beat the larger one in the ratio of about 55 to 45. This was possibly due to its greater speed in altering its conclusions concerning its opponent. Both machines are attempting to find patterns in the other and as soon as one machine finds such a pattern the other machine begins to lose and consequently changes the pattern. Thus the more volatile type has a certain advantage.

The maze solving machine which I have here is another example of a learning machine. While not learning to play a game, it does learn by experience to solve a certain type of problem. A classical psychological learning problem is to place an animal in a maze and observe the time required for it to learn its way to the food box. The maze solving machine is an attempt to dramatize in precisely the same terms how a relay circuit can learn to solve this type of problem. The partitions in the maze can be changed about at will and allow one to set up something like one thousand billion different possible mazes for the machine to solve. On its first trip through, the mouse follows an exploring strategy involving a great deal of trial and error and false moves into blind alleys. Eventually it arrives at a brass disk representing the food box. If we now place the mouse at its original starting point it goes directly to the goal with no false moves. This demonstrates that the relay circuit has learned the correct path. Furthermore if the mouse is placed in any other part of the maze that it has pre-

viously explored it will proceed directly to the goal. If it is placed in a part of the maze that it has not previously visited during its exploration phase it will blunder about until it reaches a familiar square and from there it will proceed directly to the goal. If it is now again placed in this region it will go directly to the goal. This shows that it has added the information about this part of the maze to its previous analysis. Finally, if the maze is changed the mouse first tries the old path and when this fails it starts exploring again to find another way to the goal. If the goal is blocked off so that there is no path available the mouse continuously searches through all parts of the maze that it can reach.[4]

While the developments in game-playing machines of the past, particularly in the last two decades, have been interesting and provocative, it seems certain that the next decade or two will make these devices seem primitive. The widespread use of large-scale computers and the rapid advancement of programming theory will surely result in impressive examples of general strategic machines and of game-learning machines.

[4] Here the operation of the maze solving machine was demonstrated.

Advanced Insulation for Direct Current Armored Motors.—An improved line of direct current armored motors with an advanced insulation utilizing Class H materials has been announced by General Electric Company. Motors with the new Class H insulation are coming off production lines at G–E's Direct Current Motor & Generator Department, Erie, Pa.

"This marks the first time," according to Paul S. Stough, the department's manager of engineering, "that Class H insulation has been applied to the coils of direct current motors in regular production."

The Class H insulated motor is being offered at no increase in price. Prior to the G–E announcement, Class H insulated motors and components had been offered only on special order and at a substantial price increase over Class B insulated equipment.

Company engineers said the new insulation will withstand temperatures of 180° C. Its use in normal duty, they explained, virtually eliminates insulation failure as the limiting factor in continuous armored motor service.

The new insulation system, which includes the application of a specially developed silicone varnish, was installed in the popular MD-602 model for tests in which the motor was subjected to severe overloads which produced motor temperatures as high as 200° C. Connected to it was another MD-602 with the former Class B type insulation. To maintain an equal balance between them in both load and temperature, the two motors alternately functioned as motor and generator. The motors were driven at four times their rated speed and subjected to severe vibration. The shunt field circuit was abruptly interrupted at regular intervals to produce an inductive kick which would throw electrical stress on the field coil insulation.

The tests showed the Class H insulated motor maintained excellent operating condition without apparent loss of dielectric or physical strength, contrasted with extensive burn-out damage in the motor with Class B insulation.

Demonstrated by the tests was the ability of the Class H insulated motor to outlast at least two Class B insulated motors. Engineers calculate that under identical operating conditions, Class H insulation will outlast Class B by as much as 32-to-1.

Class H insulation has been adapted to three main sections of the armored motor—the field coils, armature coils and the main area of the armature insulation. In all these sections damage has resulted in the past from high heat concentration.

Silicone treated mica mat is used on commutating and exciting field coils and on armature coils. Company engineers said that in laboratory tests this insulation has maintained full dielectric strength after samples had been heat cycled for three and one-half months at 300° C.

It was pointed out that all new G–E Class H insulated coils may be interchanged with Class B coils in older motors of the line.

Spray Away Dust and Static.—Braun Laboratories (Philadelphia, Pa.) announces Anti Stat No. 6, a new product which rapidly cleans, eliminates dust and static from all glass, plastic and film. It is odorless and colorless. Packed in a 12-oz. aerosol spray can, it is easy and quick to use wherever static and dust are problems, such as all film, gates and carriers on projectors, film holders, slide and cover glass, printers, plastic reels, film stripping, retouching, Hi-Fi recordings, etc. Anti Stat No. 6 is available in all leading camera stores.

RECENT DEVELOPMENTS IN THE TECHNOLOGY OF CERAMIC MATERIALS FOR NUCLEAR ENERGY SERVICE *

BY

J. M. WARDE [1] AND J. R. JOHNSON [1]

Ceramics—non-metallic materials capable of service at elevated temperatures—have several actual and potential applications in nuclear energy service. In particular, such materials are of interest in reactors intended for high temperature operations. They also have potential application because of their nuclear properties and corrosion resistance.

Physical research is carried out on ceramic materials under the sponsorship of the Atomic Energy Commission at a number of research institutions and it is the purpose of this paper to review some recent developments in this field.

FUEL ELEMENTS

The bulk of the recent research and development efforts on ceramics and ceramic metal combinations (cermets) has been in the fuel element field because of the relative stability of ceramics at elevated temperatures and their resistance to corrosion in certain environments.

Uranium Oxide

Many of the compounds of uranium are of interest for reactor use because of their higher service temperatures compared with the metal. In particular, the dioxide of uranium has received considerable attention because of its refractory nature and resistance to aqueous corrosion. Data on the uranium oxides are shown diagramatically in Fig. 1.

Differential Thermal Analysis

DTA-weight gain measurements in the temperature range, 20° C. to 1000° C., have been used at the Oak Ridge National Laboratory as a method for rapidly indicating the oxygen contents and the reactivities fo UO_2 powders prepared by various techniques. Figures 2 and 3 show some DTA weight-loss data for selected UO_2 powders. The DTA and weight-change curves indicate two oxidation steps $UO_2 \rightarrow U_3O_7 \rightarrow U_3O_8$. Both steps are exothermic. The initial oxides studied vary from $UO_{2.005}$ to $UO_{2.15}$, and in general the intermediate oxides vary from $UO_{2.34}$ to $UO_{2.38}$. These oxygen ratios were calculated on the basis that

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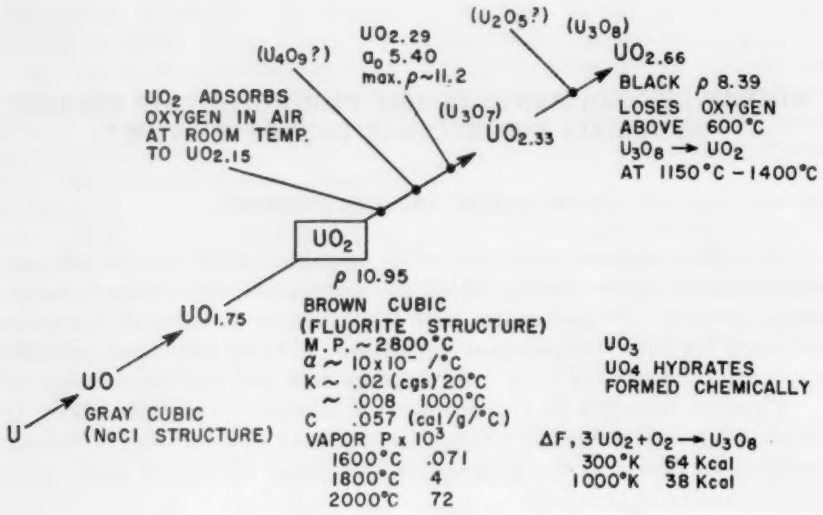

FIG. 1. Data on uranium oxide.

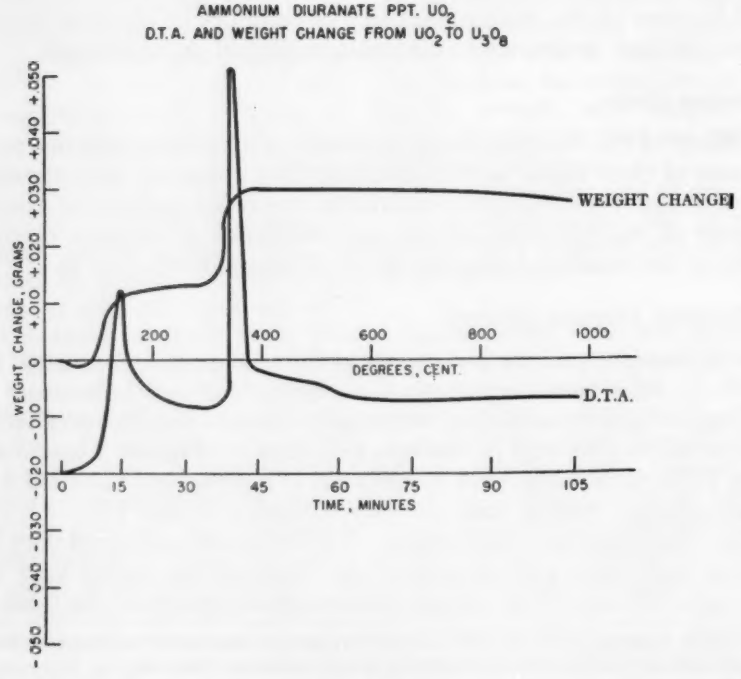
AMMONIUM DIURANATE PPT. UO_2
D.T.A. AND WEIGHT CHANGE FROM UO_2 TO U_3O_8
WEIGHT CHANGE
D.T.A.
WEIGHT CHANGE, GRAMS
+.050 +.040 +.030 +.020 +.010 0 -.010 -.020 -.030 -.040 -.050
200 400 600 800 1000
DEGREES, CENT.
0 15 30 45 60 75 90 105
TIME, MINUTES

FIG. 2.

the uranium oxide was U_3O_8 at the maximum weight shown on the curves. In all cases a small weight loss, 0.0001 to 0.001 gram per gram of UO_2, was observed between 50° C. and 150° C. This loss in weight is probably due to adsorbed water. The effects of particle size and degree of crystallinity of UO_2 powders on their reactivity and the final density of bulk UO_2 shapes made from them are being studied by this technique. It is observed that UO_2 prepared by methods yielding very

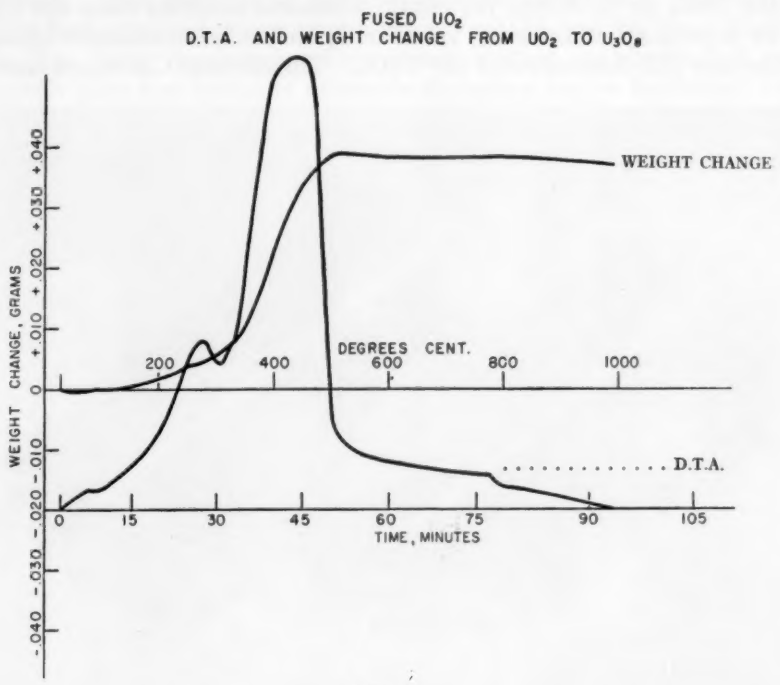

FIG. 3.

small crystals react at lower temperatures whereas the oxides having large crystallites or small surface areas react more slowly at higher temperatures. By proper selection of starting materials, UO_2 in bulk form has been prepared by isostatic pressing and sintering at 1750° C., resulting in bodies having 96 per cent theoretical density (see Fig. 4).

Thorium Oxide

Thorium oxide of potential interest as a breeder material is required in the form of shapes having maximum density. It has been found at ORNL (1)[2] that the addition of 0.5 wt. per cent CaO will produce bulk ThO_2 shapes having densities of 96 per cent of theoretical compared with 86 per cent for those made using ThO_2 without additions under the

[2] The boldface numbers in parentheses refer to the references appended to this paper.

same firing conditions, that is, 1700° C. for 1 hr. (See Fig. 5.) A study of the effect of the addition of CaO indicates that the calcium is taken into solid solution in the ThO_2 ,producing anion vacancies. The diffusion of Th^{++++}, O^{--} and Ca^{++} is accelerated as a result of the vacancies and more rapid sintering occurs. The Ca^{++} ion has about the same ionic radius as Th^{++++}, about 1 Å, so that solid solution is expected. A lowering of the index of refraction is noted as CaO is added to the ThO_2 up to 20 mol per cent. Chemical analyses show the CaO to be present after sintering, yet there is almost no measurable change in the unit cell dimensions of the ThO_2. The effect of CaO upon sinter-

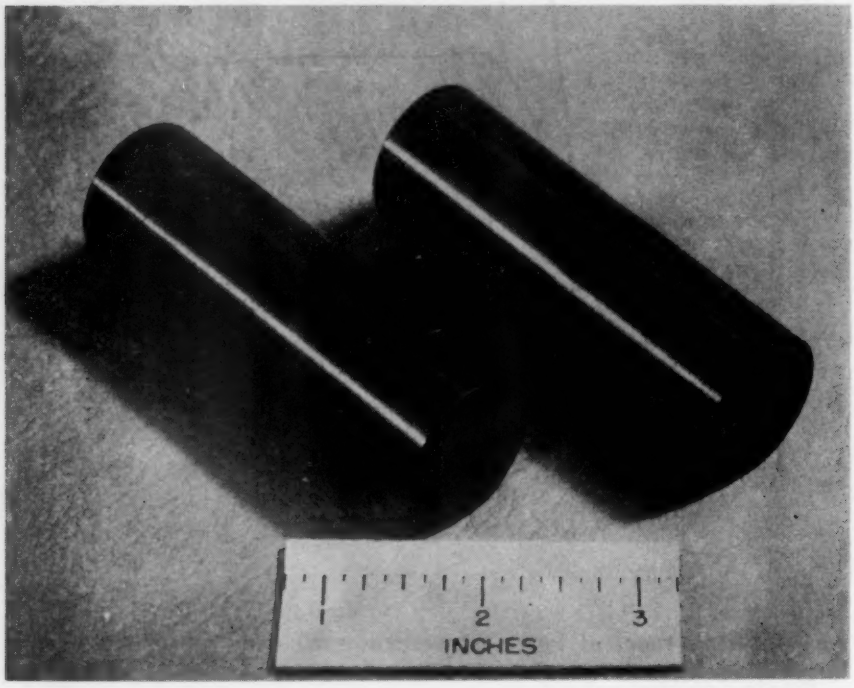

Photo courtesy Oak Ridge National Laboratory

FIG. 4. UO_2 rods, density 96 per cent of theoretical.

ing is noted beginning at 1100° C. and is pronounced at 1600° C. There is no liquid phase in the ThO_2-CaO system below 2300° C. so that this is a solid state reaction. An investigation of the sintering rates indicates that surface diffusion is primarily responsible for the rapid densification of the ThO_2-CaO compacts. The mobility of Ca^{++} on the surface of ThO_2 at high temperatures is high and almost immediately the pores in the pressed compacts are filled to the closed pore state. Volume diffusion of the Ca^{++} and the Th^{++++} and O^{--} through the defect structure is much less rapid than migration over the surface but

is sufficiently rapid to maintain increased sintering rates in the closed pore state.

Cermets

Ceramic metal combinations offer interesting possibilities for use in fuel element fabrication and for structural components of nuclear reactors. Two cermets of possible interest for reactor applications which have received recent attention are Cr-Al_2O_3 and SiC-Si. Work at the Ohio State Engineering Experiment Station (2) shows that consistently pore free bodies of moderate shrinkage can be fabricated from

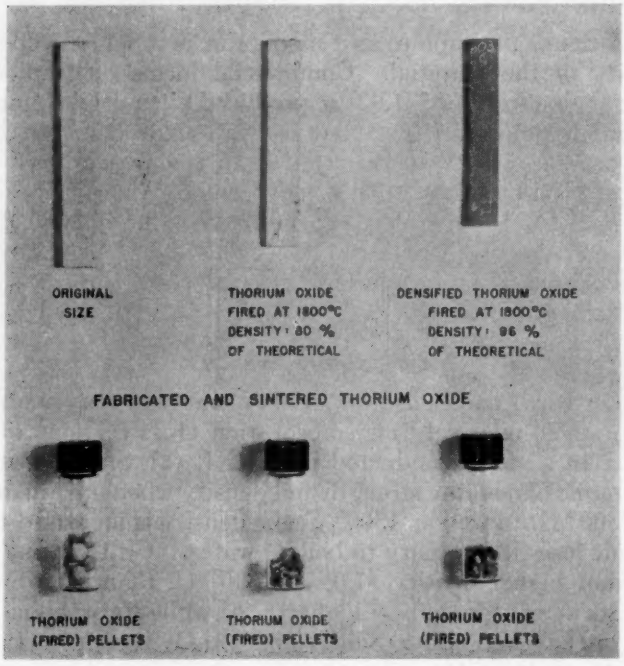
ORIGINAL SIZE
THORIUM OXIDE FIRED AT 1800°C DENSITY: 80 % OF THEORETICAL
DENSIFIED THORIUM OXIDE FIRED AT 1800°C DENSITY: 96 % OF THEORETICAL
FABRICATED AND SINTERED THORIUM OXIDE
THORIUM OXIDE (FIRED) PELLETS
THORIUM OXIDE (FIRED) PELLETS
THORIUM OXIDE (FIRED) PELLETS

Photo courtesy Oak Ridge National Laboratory

FIG. 5. Thorium oxide ceramics.

the compositions 72 per cent chromium-28 per cent alumina to give bodies having a density of 5.9. High temperature strength properties may be adequate for applications at 800° F. and above. Oxidation of this material is negligible at temperatures below 2000° F. The sustained load carrying ability shown by stress rupture behavior indicates that deterioration as a function of time is not extensive below 2000° F. Thermal shock resistance for this material is reported to be good. Siliconized silicon carbide may be prepared by the impregnation of a porous graphite body with molten silicon. The thermal neutron ab-

sorption cross section of this material is about 0.1 barn. Studies at ORNL (3) resulted in the production of non-porous bodies of this material. The final density of this SiC-Si is 3.1; tensile strength at room temperature is about 10,000 psi., and thermal conductivity is better than that of stainless steel.

Silicon carbide bodies using SiN as the bonding agent and reported to have less than 10 per cent porosity have been developed. Self bonded silicon carbide density 96 per cent of theoretical has also been produced (4).

MODERATORS

High Density Graphite

The efficiency of graphite as a moderator is roughly proportional to the density of the material. Commercial forms of graphite having densities ranging from 1.85–1.92 are produced by multiple impregnations of graphite with pitch. The average value for transverse breaking strength of 1.92 density material at room temperatures is 4500 psi.; modulus of elasticity 2.5×10^6 psi.; thermal expansion at 200° F. is reported as 1.1×10^{-7} per deg. F.; thermal conductivity in Btu per hr. per sq. ft. per deg. F. per in. is 1200. The high density material has very good erosion resistance in high velocity gases compared with that of commercial graphite.

CONTROL ROD MATERIALS

The rare earth oxides are materials of interest for reactor controls because of their relatively high absorption cross sections for thermal neutrons. In a study conducted by ORNL (5), Sm_2O_3 was found to form a ceramic of medium strength and density when fired in dry pressed form at 1300° C. Fired at 1500° C. the density is increased to 7.4 and the ceramic loses its stability to boiling water. Gd_2O_3 forms a ceramic of somewhat higher density (7.0) at 1300° C. than does Sm_2O_3. At 1500° C. its density is slightly higher (7.6) while its stability in boiling water is unchanged. Both Sm_2O_3 and Gd_2O_3 form compounds with Al_2O_3, BaO, Fe_2O_3, SiO_2 and SrO. The alumina and iron compounds have the perovskite structure previously observed in the case of yttria-alumina.

Hafnium oxide is also of potential interest as a reactor control material and investigation of this material at ORNL (6), indicated that hafnium oxide closely resembles ZrO_2. HfO_2 forms a continuous series of solid solutions with ZrO_2 and it forms a single compound with silica, $HfO_2 \cdot SiO_2$, similar to zircon. Monoclinic HfO_2 is stable to 1700° C.; the tetragonal form is found above this temperature. Boron carbide of compositions B_4C and B_6C have been produced in bulk form and also offer promise for control or shielding applications. Figure 6 shows specimens of HfO_2, Sm_2O_3 and Gd_2O_3.

COATINGS

Ceramic coatings developed for service at 1000° C. have been prepared by the National Bureau of Standards (**7**) from materials having low absorption cross sections for thermal neutrons. They were specifically designed for application to typical high temperature alloy parts for use in nuclear reactors. In these coatings, high-barium frits containing small amounts of phosphates, beryllia, lime, zinc oxide and titania are milled with additions of ceria or mixtures of chromic oxide and ceria. The computed neutron absorption cross sections are in the range of 0.15 to 0.50 barn. In extended heating tests some corrosion was noted beneath the coatings but the amount and depth were markedly reduced over uncoated specimens. The best coatings withstood the thermal shock encountered when quenched from 2000° F. in water at room temperature.

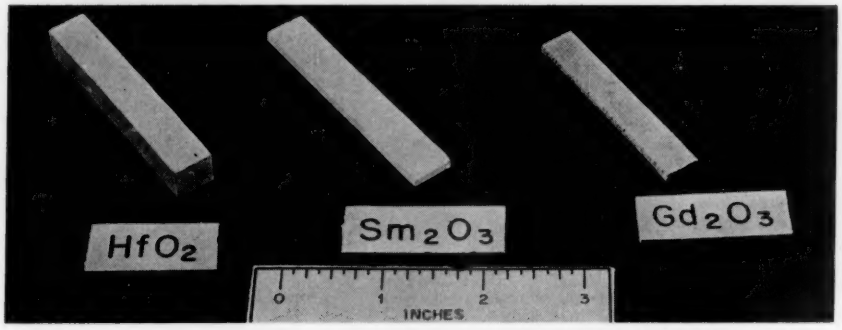

Photo courtesy Oak Ridge National Laboratory

FIG. 6. Some ceramics of interest (high cross-section).

CORROSION

High temperature corrosion studies were conducted on refractory materials in liquid sodium, bismuth and tin (**8**). Ceramic materials exhibiting good resistance to corrosion by sodium liquid-vapor were reported as follows: Synthetic sapphire, single-crystal magnesia, molybdenum disilicide and sintered thoria. The following ceramic materials show a good resistance to liquid bismuth: graphite (to 1400° F.), sintered magnesia, sintered alumina, sintered zirconia, molybdenum disilicide, tantalum carbide, "Vycor" and "Kennametal" (K138A). The following ceramics showed good corrosion resistance to molten tin: graphite (to 1500° F.), "Vycor," chromium carbide (to 1500° F.) and sintered alumina.

RADIATION EFFECTS

Stability of ceramic materials under irradiation is of fundamental importance in nuclear reactor applications. A comprehensive survey

of the radiation stability of ceramic materials is being carried out by ORNL. Data have been collected on a number of ceramics which were subjected to irradiations of 1×10^{20} and 2×10^{20} *nvt*, respectively. The thermal conductivity at about 40° C. has been measured by Sisman, Bopp and Towns (9) on the irradiated ceramic specimens. These data are shown in Table I. X-ray diffraction indicated disordering in some

TABLE I.—*Thermal Conductivities*[a] *of Irradiated Ceramics*[b].

	Thermal Conductivity (10^{-4} cal·sec^{-1}·cm^{-1}·° C^{-1})		
		Postirradiation[c]	
Material	Preirradiation	$nvt = 1 \times 10^{20}$	$nvt = 2 \times 10^{20}$
Silica glass	35		35
Single-crystal Al_2O_3	>300		>300
Hot-pressed Al_2O_3	>300		>300
BeO	>300		>300
TiO_2	200	120	110
Spinel	>170	100	100
Forsterite No. 243	180	43	43
Cordierite No. 202	77	23	21
HfO_2	80	30	30
Steatite No. 228	60	28	28
Mica	21	14	13
ZrO_2 No. 550	33		25
Zircon No. 475	120		21
Zircon No. 71	49		28
Plate glass	30	30	30
Pyrex glass	36	30	20
Lead glass	16	10	10

[a] In the temperature range from 35 to 45° C.
[b] C. D. BOPP, O. SISMAN AND R. L. TOWNS, "Solid State Semiann. Prog. Rep. Aug. 30, 1954," ORNL-1672 p. 90.
[c] Exposures are given in epithermal neutrons.

crystalline materials. In some cases decreases in thermal conductivity were found where no changes were detected in X-ray diffraction patterns. Zircon irradiated to 2×10^{20} neutrons per sq. cm. gave very low and poorly reproducible thermal conductivity before a thin surface was removed by scraping. For many of the materials there was not much additional change in thermal conductivity with the longer exposure (2×10^{20} neutrons per sq. cm.). It was suggested that possibly the change is approaching saturation. X-ray diffraction patterns of the irradiated specimens were made by Klein (10) and qualitatively compared to the patterns of the corresponding samples before irradiation and the results are shown in Table II. It should be noted that the method of X-ray analyses for polycrystalline samples with a high activity count is not so sensitive in detecting weak X-ray reflections as the method used for small single crystals of the same materials. Consequently, where the method used in this study would indicate the absence of detectable diffraction lines in certain cases, the single crystal analysis might still indicate a few weak reflections remaining in the film pattern after a comparatively long exposure time.

Under irradiation, quartz alters gradually to an amorphous form.

TABLE II.—*X-Ray Examination of Ceramic Samples.*

Sample	Results When Irradiated with 1×10^{20} neutrons/cm²	Activity (at 1 cm)	Results When Irradiated with 2×10^{20} neutrons/cm²	Activity (at 1 cm)
Single-crystal Al_2O_3	No change in pattern	1.5 mr/hr	No change in pattern	1.5 mr/hr
Hot-pressed Al_2O_3	No change in pattern	6 mr/hr	No change in pattern	10 mr/hr
Spinel	No change in pattern	1.5 mr/hr	No change in pattern	5 mr/hr
Forsterite	No change in pattern	15 mr/hr	No change in pattern	60 mr/hr
Porcelain	No change in pattern	40 mr/hr	No change in pattern	40 mr/hr
Steatite	No change in pattern	80 mr/hr	No change in pattern	80 mr/hr
TiO_2	No change in pattern	170 mr/hr	No change in pattern	230 mr/hr
Silica glass	Halo broadening	2 mr/hr	Halo broadening	2 mr/hr
Plate glass	Halo broadening	10 mr/hr	Halo broadening	15 mr/hr
Pyrex glass	Halo broadening	10 mr/hr	Diminution in halo intensity; broadening	30 mr/hr
Lead glass*	Lead plus other devitrification products	500 mr/hr	Lead plus other devitrification products	900 mr/hr
Mica	Line broadening; 1.3% expansion in c_0	120 mr/hr	Line broadening; 1.7% expansion in c_0	170 mr/hr
Enamel ground coat	Loss in crystallinity	6.7 r/hr	Loss in crystallinity	11 r/hr 7 r/hr (gamma)
ZrO_2	No change in pattern	6 r/hr	0.28% expansion in a_0	10.4 r/hr 600 mr/hr (gamma)
Hf-free ZrO_2	Diminution in monoclinic phase	800 mr/hr	Monoclinic phase disappears; cubic phase remains	1.2 r/hr
Zircon	1.9% expansion; large loss in crystallinity	2.2 r/hr	No lines detectable; large loss in crystallinity	6.8 r/hr
SiC	Line broadening; 0.3% expansion	10 mr/hr	Expansion and loss in crystallinity	10 mr/hr
BeO	Very slight expansion in c_0	9 mr/hr	Approximately 0.3% expansion in c_0; none in a_0	25 mr/hr
Lava	Loss in crystallinity	170 mr/hr	No lines detectable	220 mr/hr
Cordierite	No change in pattern	100 mr/hr	Line broadening	150 mr/hr
MgO	No change in pattern	15 mr/hr	$MgO + MgO \cdot 4CO_2 \cdot 5H_2O + MgCO_3 \cdot 3H_2O$	15 mr/hr
$BaTiO_3$	2.03% expansion in a_0	80 mr/hr	2.87% expansion in a_0; reflections broadened	170 mr/hr

* Confirmed by petrographic analysis.

Some of the property changes reported by Wittels, Oak Ridge National Laboratory (11), and Primak, *et al.*, of Argonne National Laboratory (12), are decreases in density, refractive indices, and birefringence, disappearance of the alpha to beta transition and changes in the absorption spectrum. The properties of vitreous silica also alter under irradiation. The density and refractive indices increase slightly. On heating the irradiated quartz and other forms of silica, the properties are reported to alter in a complex manner.

OTHER APPLICATIONS OF CERAMICS IN NUCLEAR ENERGY

Present methods of disposing of radioactive wastes are safe for limited quantities but in many cases, extremely expensive. Work is being done on the application of cheaper methods of handling such wastes (13). One possibility which has received serious study at the Brookhaven National Laboratory is a method of adsorbing the wastes on clay pellets. The pellets are then glazed in a furnace so that the products cannot seep out and it is proposed that these pellets can be safely buried. Various clays and other minerals have been found under certain conditions of pH and temperature to have a great affinity for radioactive wastes. Table III shows the result obtained in jar tests on

TABLE III.—*Removal of Radioactive Materials by Various Clays.*
(Brockett and Placak)
(Jar Stirring Method with 1 Gram of Clay)

Sample Number	Type of Clay Locality	Per Cent Removals after 2-hr Contact						
		Ce^{144} 3.9×10^{-2} uc/ml	P^{32} 3.5×10^{-2} uc/ml	Ru^{106} 4.8×10^{-2} uc/ml	Sr^{89} 1.1×10^{-2} uc/ml	Sr^{90} 4.1×10^{-2} uc/ml	Zr^{95} 0.78×10^{-2} uc/ml	MFP* 4.1×10^{-2} uc/ml
1.	Kaolinite Mesa, Alta, N. Mex.	92.50	51.58	69.39	30.40	46.25	98.08	70.87
2.	Halloysite Eureka, Utah	91.82	72.90	77.95	26.15	61.63	98.32	89.77
3.	Montmorillonite Little Rock, Ark.	69.21	88.27	64.40	63.03	74.50	97.18	94.70
4.	Montmorillonite Cameron, Ariz.	89.00	31.89	52.89	57.44	71.35	91.05	92.44
5.	Nontronite Manito, Wash.	85.16	44.56	60.77	29.26	71.49	92.25	94.75
6.	Metabentonite Tazewell, Va.	76.05	68.28	53.61	16.10	53.46	83.59	86.20
7.	Metabentonite High Bridge, Ky.	88.20	80.05	68.08	41.75	59.87	97.13	86.16
8.	Conasauga Shale Oak Ridge, Tenn.	90.91	72.67	71.69	14.15	55.69	96.63	86.88
9.	Vermiculite (nonexpanded) Sylva, N. C.	95.94	60.15	68.69	26.77	65.53	93.87	—

* Mixed fission products ~16% Ce^{144}, ~20% trivalent rare earths, ~2% Ru^{106}, ~20% Sr^{90}, 21% Cs, ~21% unknown.

the removal of radioactive materials by various clays and vermiculite as reported by Brockett and Placak (14). They point out that base-exchange ratings do not indicate the efficiency of clays or soils for re-

moving radioactive materials from solution and further conclude that although certain removals are obtained with one chemical form of radioisotope it does not necessarily follow that the same results will be obtained with other chemical forms of the isotope.

At ORNL studies are being carried out on the possibility of incorporating radioactive liquid wastes in a ceramic body in pits and fixing

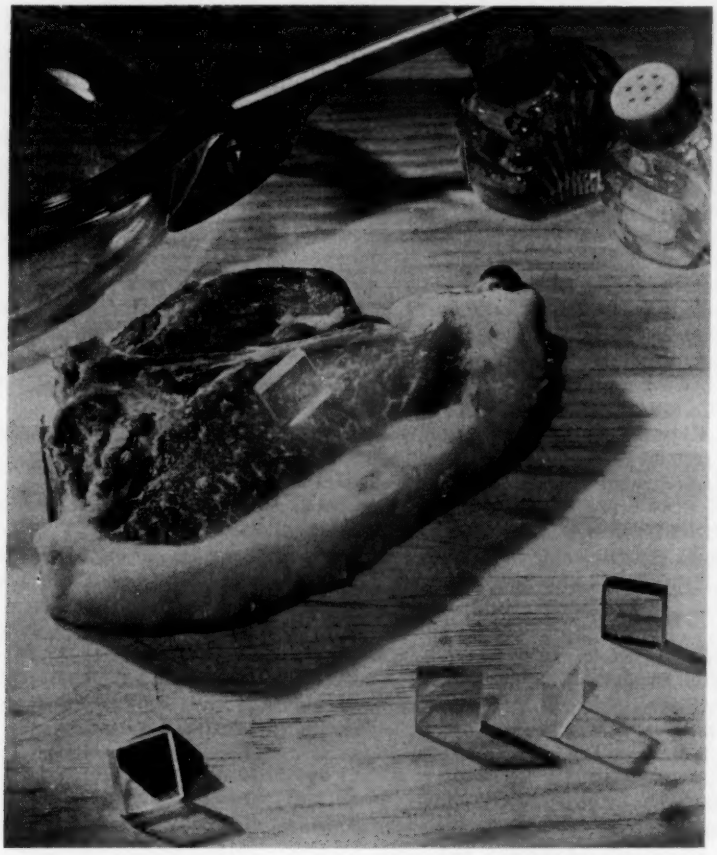

Photo courtesy Corning Glass Works

FIG. 7.

the dangerous isotope by sintering the mass in place using the heat available from radioactive decay.

Contributions in the field of glass technology include the development of windows which do not darken under radioactive bombardment. Such windows are necessary in order to see into the ray filled interiors of hot labs. These windows are so heavy that one measuring 6 × 8 ft. weighs about 12 tons (**15**). Another interesting development in the

glass industry has been the manufacture of radiation dosimeters which are pieces of silver activated phosphate glass that indicate by darkening the amount of radiation to which they have been exposed. They are finding use in studies made in the food sterilization field. Figure 7 shows how the degree of sterilization of pork by radiation may be indicated by squares of dosimeter glass which change color according to the amount of radiation received (16).

Glass and glass-metal pipes and valves may be of interest in future handling of radioactive process solutions. Tests at ORNL indicate no gross damage to commercial glass-piping and glass-metal specimens in such solutions having an activity level of 10^8 counts per min.

This short summary has covered some of the highlights in the developments in ceramics for nuclear energy service and it is hoped that it will serve to give an indication of the applications of ceramics in nuclear energy service.

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POLARIZATION IN THORIUM OXIDE CRYSTALS *

BY

W. E. DANFORTH [1] AND J. H. BODINE [1]

ABSTRACT

Studies have been made of the electrical polarization resulting from the passage of current in single crystals of low-oxygen thorium oxide at elevated temperatures. The emf. across the crystal necessary to maintain a constant current rises by a factor of 100 and more during the establishment of the final equilibrium. Because of the wide ranges of time involved, observations were required with oscillographic techniques as well as long time measurements using a slide wire potentiometer. The resistivity of the material was found to vary from 6000 ohm-cm. at 900° C. to 400 ohm-cm. at 1300° C., and to be unchanged by large values of polarization. Indications point to a critical potential for the onset of electrolysis in the neighborhood of 0.3 volt. The dependence of initial conductance upon temperature point to an activation energy for the initial conductance of 1.1 *e*-volts and the same temperature dependence is approximately valid over the whole polarization curve. Theoretical considerations indicate that ions and electrons are both mobile and, to account for the high polarization ratios, it appears that the fraction of current carried by the electrons is less than 1 per cent of the total.

A. INTRODUCTION

Our previous work has established the existence of several color states in thorium oxide as determined by oxygen content and heat treatment (1).[2] We have reported data concerning electrical conduction of single crystals in an atmosphere of oxygen (2). The present paper is concerned with conductivity phenomena in that low oxygen state which exists in high temperature and high vacuum operation.

When one attempts to measure the conductivity of a thoria crystal in vacuum or to determine any other electrical property, one encounters very prominent time changes which make the intended measurement difficult. If a fixed voltage is applied to the crystal, the current starts at a definite value and decays rapidly. Or, if a constant current is passed, the voltage across the crystal rises to a definite value at the moment the current is initiated and then continues to increase with time to a value many times the initial value. It was apparent, therefore, that to understand the d-c. behavior of thorium oxide it was necessary to study in some detail the time variations which take place.

The existence of the time changes would be expected if an appreciable proportion of the conduction were ionic; a previous experiment (3) has given visual evidence of electrolysis. One objective of the present study is to evaluate quantities pertaining to number and mobilities of ions.

* Assisted by the U. S. Navy Bureau of Ships and by the Office of Ordnance Research.

[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

While theoretical considerations relative to this are incomplete and are referred to only briefly in the present paper, it appears probable that the conductance of a crystal at 1300° ($\sim$0.0025-ohm^{-1} cm.$^{-1}$) unpolarized and unelectrolyzed, is less than 1 per cent electronic. The high electronic conduction of thorium oxide in its application as a cathode emitter appears to depend upon the presence of electrolytically produced thorium.

This paper describes the phenomena observed when a constant current is passed through a crystal of thorium oxide in vacuum and at the temperatures ranging from 900° C. to 1300° C. Although higher temperatures are of interest, investigation of them was not possible in the present experiments because of the use of platinum as an electrode material. Certain aspects of this work have been presented briefly (**4**, **5**) elsewhere.

B. EXPERIMENTAL

1. General Pattern of the Phenomena

The basic phenomenon here discussed is illustrated in Fig. 1 (*a* and *b*). A constant current is passed through the specimen (Fig. 1*b*) and

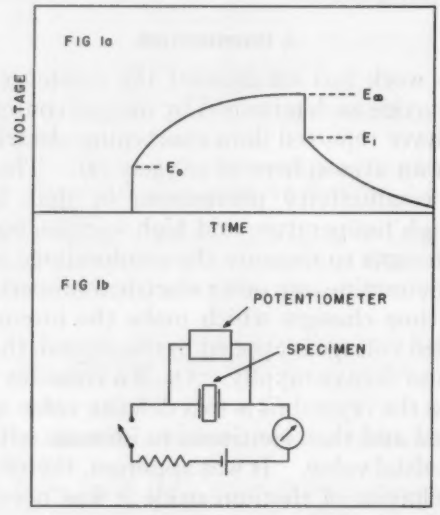

FIG. 1.

(*a*) Schematic representation of the polarization phenomenon.
(*b*) Circuit for observing polarization at constant current.

the potential across the specimen is observed with a potentiometer. When the switch is closed the potential rises abruptly to E_0 (Fig. 1*a*) and then continues to increase in time to an equilibrium value E_∞. If after equilibrium is attained the switch is opened, the potential falls abruptly

from E_∞ to E_1 after which it decays slowly back to zero. In data thus far examined the drop $E_\infty - E_1$ on interrupting the current is very nearly equal to the initial rise E_0. At any time after initiation of the current the potential difference which remains when the current is turned off is called the *polarization*. The abrupt fall which occurs when the current is interrupted (as shown by $E_\infty - E_1$ for the equilibrium case), divided by the value of the current, will be defined as the *total resistance* of the specimen in the given state of polarization.

2. *Character of the Specimens*

The studies here reported were made in a vacuum furnace at temperatures between 900° C. and 1300° C. The specimens were cut from fused lumps obtained from The Norton Company and appeared macroscopically to be single grains; their dimensions were approximately 5 mm. × 5 mm. × 2 mm. The surfaces were ground flat using 600-mesh Carborundum on an iron lap and were not polished. As regards purity, there appeared no practical alternative to using the material as received from the supplier; spectrographic arc analysis revealed aluminum and lanthanum as the principal impurities, both present to the order of magnitude 0.01 per cent. Traces of chromium, copper, silicon, beryllium, titanium, cerium, yttrium and zirconium were also reported.[3]

After a crystal had been cut to size and smoothed on the lap, platinum electrodes were applied to a pair of opposite faces by evaporation. Contact leads of platinum foil were affixed to the platinum electrode by holding them in contact with the evaporated platinum surfaces for a short time at 1400° C.; this resulted in an adequate weld.[4]

It was found necessary to shield the specimen electrostatically from the a-c. field of the heating coil of the vacuum furnace. Stray and variable thermionic emission from the leads is the principle source of disturbance; inductive pick-up is of secondary importance although not zero. Shielding was accomplished by the coaxial assembly shown in Fig. 2. It was found that a crystal mounted in this assembly, even though well shielded, may show a potential difference between electrodes of a few hundredths of a volt. This is thought to be due to temperature inequalities.

[3] Obviously it would be desirable to prepare a sufficient quantity of thoria of extremely high purity and to grow single crystals, perhaps by evaporation. The effort involved in this would be very considerable. The value of the results with the presently available materials seems to us two-fold: (1) Even though it might be shown later that phenomena are more or less impurity dependent, the general character of the phenomena is of interest and the techniques and methods of analysis will be applicable to high purity materials; (2) The results here reported are pertinent to thorium oxide *as it is actually used* in electron tube applications.

[4] It was found that, at 1400° C. in vacuum, platinum may be said to "wet" thorium oxide; if a piece of platinum foil is held firmly against the crystal at this temperature, firm adhesion results.

3. Long-Time Observations

In Fig. 3 are plotted curves of the polarization voltage as followed by a Leeds and Northrup type K potentiometer for several different values of current. After each run the specimen was allowed to remain

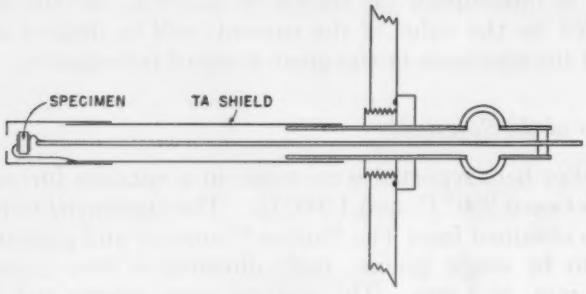

FIG. 2. Shielded specimen mounting for use in vacuum furnace.

hot with the current off until the polarization had returned to a low value. The temperature of the specimen was 1300° C. Essentially similar results were obtained with two different specimens.

One sees that several hours are required for the attainment of an equilibrium voltage; in fact, it is not certain but that even after 7 hr. a

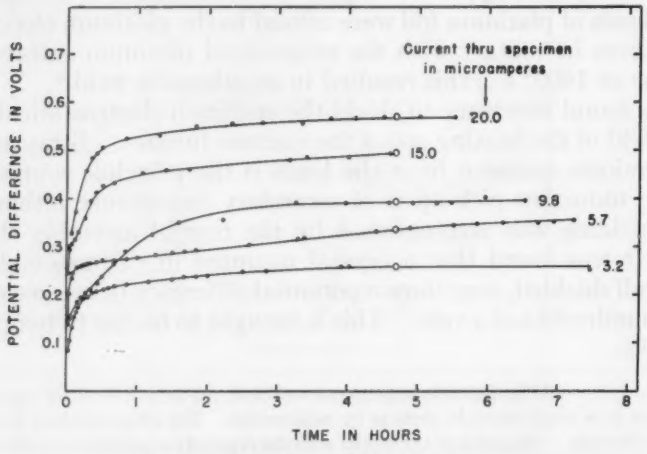

FIG. 3. Long-time polarization curves.

slow upward drift of the potential may still occur. One also sees that, on this time scale, it is not possible to discern an abrupt initial rise; one cannot make a meaningful extrapolation of the data to zero time. Oscillographic studies are required in order to do this, and will be

described below. Figure 4 shows a plot of the voltage which had developed after 4 hr. of current flow plotted against the value of the current. Although some further increase of voltage with time might be expected, it is assumed that the general character of the relationship between equilibrium voltage and current will not be radically different from that shown. One sees that as the current is increased, the voltage rises more or less linearly to a knee and from there on proceeds linearly with a considerably reduced slope. The value of voltage corresponding to the knee is approximately 0.3 volt.

We call attention here to the similarity between the present phenomena and the situation which obtains in the case of common aqueous electrolytes; in that case, the value of electromotive force corresponding to the knee is referred to as the decomposition potential of the system.

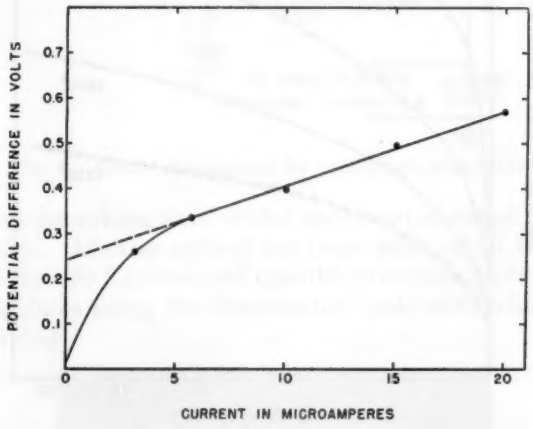

FIG. 4. Equilibrium-polarization voltage *vs.* current.

For aqueous electrolytes, this is the potential below which no "plating-out" of electrolytic product takes place, and below which the current flow is very small. With these systems, the only mobile carriers are positive or negative ions; no free electrons are present, and, therefore, unless electrolytic decomposition is occurring no carriers are available. In the present case, however, we are concerned with systems in which conduction proceeds by means of electrons as well as by ions, and, therefore, the current which can flow for voltages below the decomposition potential may be considerable. In Fig. 5 are plotted curves which show the effect of temperature upon the long-time polarization phenomena. Data were obtained for four Centigrade temperatures namely, 1155°, 1230°, 1300° and 1350°, the current being 5 microamperes in all cases. In order to obtain a wide range of temperatures, the observations were taken as low as 1155° C. However, this resulted

in the potentials rising considerably above the decomposition potential and, therefore, the run was only continued for 10 min. Using the values of polarization after 10 min., a plot was made of the logarithm of the polarization *vs.* reciprocal temperature and the slope of the curve yielded a fictitious activation energy of 1.0 electron volt.

As a component of the whole empirical pattern, it would be desirable to have data regarding the temperature dependence of the equilibrium voltage. Because of the long times required to obtain this data, and because of variations of background emf., this information is not in very

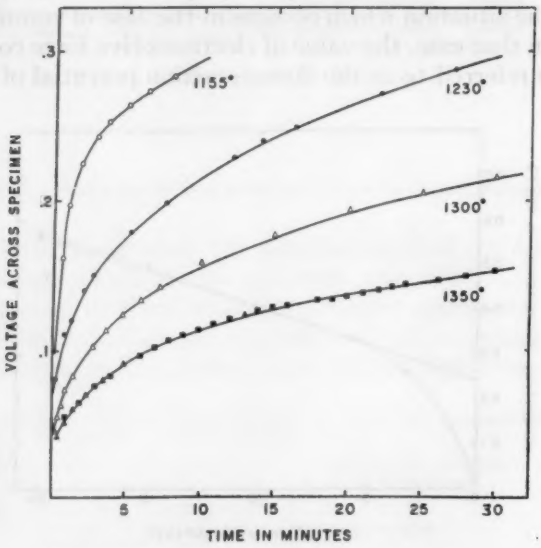

FIG. 5. Effect of temperature on polarization.

satisfactory form at the present time. It may be said, however, that the shape of the curves does not seem to be a pronounced function of temperature, and that, therefore, the empirical activation energy for the equilibrium values would not be expected to differ much from that obtained at 10 min.

4. Short-Time Observations

It was mentioned above that it was difficult to extrapolate to zero time the curves obtained with the type K potentiometer. The phenomena following the initial increase are so rapid that uncritical extrapolations, even when they appear feasible, are entirely misleading. For this reason, oscillographic means were resorted to for examination of the phenomena during the first few seconds after establishment of the current. The simple circuit for this purpose is shown in Fig. 6. The es-

sential phenomena are shown in the oscillogram of Fig. 7, and follow the pattern given schematically in Fig. 1*a*.

The first matter of interest in the short-time measurements is the value of the conductivity at the initial instant, and the variation of this conductivity with temperature. For this purpose, the calibration of the type 304-A DuMont Oscilloscope was used, after satisfying ourselves as

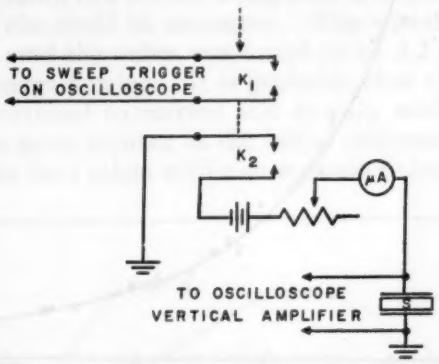

FIG. 6. Circuit arrangement for oscillograph observations.

to its accuracy by taking data with a specimen replaced by a resistance of known value. Photographs of the trace were taken with a DuMont Oscillograph Record Camera and quantitative data were taken directly from the negatives using the illuminated scale with which the oscilloscope is provided.

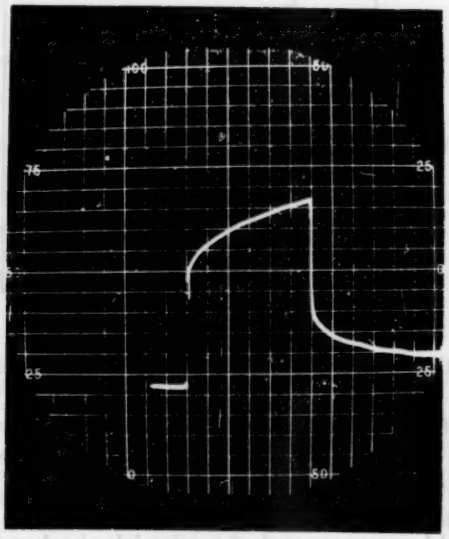

FIG. 7. Oscillogram of short-time polarization.

From values of current and of the initial voltage rise the initial resistance of the specimen was computed and this is plotted against temperature in Fig. 8. One sees that values of resistance ranging from

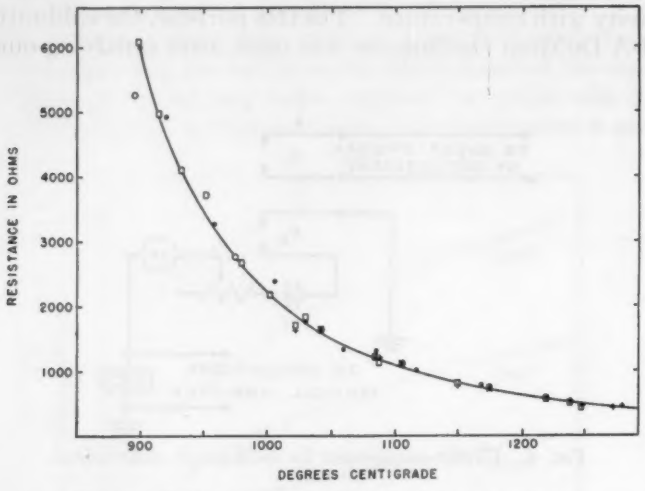

FIG. 8. Resistance of ThO_2 specimen *vs.* temperature.

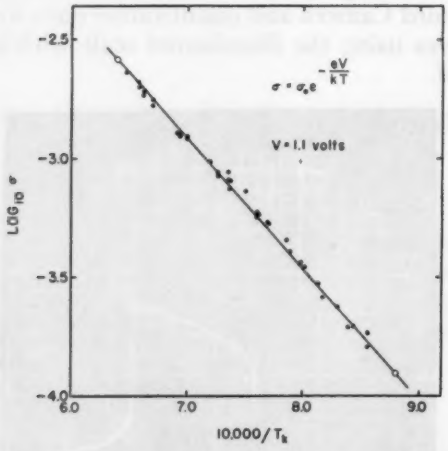

FIG. 9. Logarithm of conductivity of ThO_2 *vs.* reciprocal temperature.

6000 ohms at 900° C. to 400 ohms at 1300° C., were obtained. The geometry of the specimen was such that the specific resistivity was very nearly equal to the resistance.

In Fig. 9 is given the customary plot of log σ *vs.* $1/T$ using the above data. Reasonable agreement is found with the hypothesis of a single

activation energy and its value is computed to be 1.1 volts.[5] An exhaustive study of the rate of rise of polarization immediately following the initial rise of potential has not as yet been made; this is primarily because means for its theoretical interpretation are not yet available. Mathematical studies of the matter are in progress. At the present time, a single value for this rate of rise may be quoted. By using a sweep in which 1/120th of a second was spread to about 1 inch of screen, the initial rate of rise could be measured. This was done for one case, namely 1040° C., and the value was found to be 3.2 volts per second with 20 microamperes flowing. It is probable that this value will be found to be proportional to current and to vary with temperature in approximately the same manner as the initial resistance.

Figure 10 shows data taken with a slow sweep to include phenomena

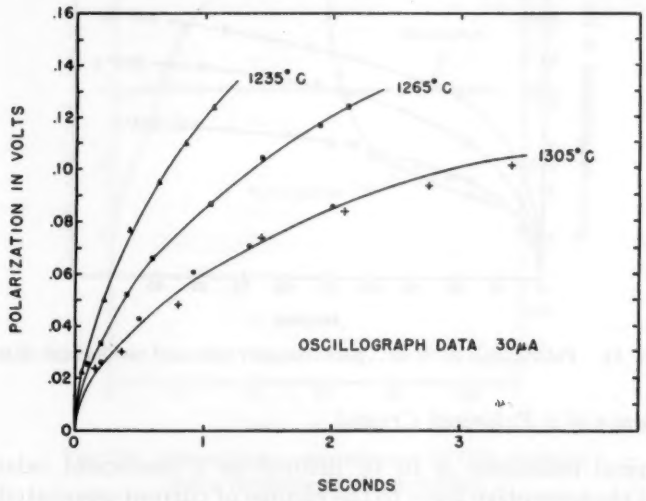

FIG. 10. Short-time polarization; oscillograph data.

between the initial instant and $t = 3$ sec. Curves were taken at three temperatures and it can be seen that over the range of the temperatures involved, the functional dependence is not markedly altered. For all curves, a good fit may be obtained by the form

$$V = kt^n,$$

where $n = 0.39$ at 1235° C., 0.38 at 1265° C., and 0.37 at 1305° C.

[5] If one could assume that the conductivity involved here was predominantly electronic, one could attempt to correlate the data given herewith with ultraviolet absorption data. Indeed, one does find an absorption band at 3 volts which might, perhaps, be associated with an energy gap at 2.2 volts corresponding to the activation energy of 1.1 volt. However, it appears now that this approximate correlation is fortuitous, inasmuch as other indications point to the initial conductivity being almost entirely ionic in nature.

In Fig. 11 we show the result of a study which was made to assure ourselves that the short-time data obtained with the oscilloscope are consistent with the long-time data obtained with the type K potentiometer. The figure shows the short-time data between 0 and 3 sec., and the long-time data beginning for the most part at about 20 sec. and continuing to 90 sec. In the case of the 1305° C. data, we succeeded in obtaining one potentiometer point for $t = 5$ sec.; the agreement of this with the oscillograph measurements is satisfactory.

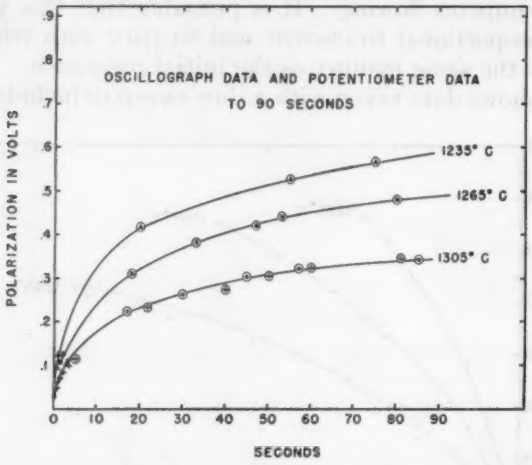

FIG. 11. Polarization to 90 sec.; potentiometer data and oscillograph data.

5. Resistance of a Polarized Crystal

Electrical resistance is to be defined as a coefficient relating the change of electromotive force to the change of current associated with it. Thus, one may have what is commonly called a "dynamic" resistance, a small change of potential divided by the small change of current which caused it, the change of current being small compared to the total current flowing. Or we may speak of the "total" resistance; the instantaneous change of potential which occurs when the current is reduced to zero, divided by the current value. It is conceivable that both of these quantities would be dependent upon the state of polarization of the crystal. It has been observed, however, that they are both relatively independent of this circumstance.

Figure 12 shows measurements of the dynamic resistance of the specimen made while the polarization increased. One sees that, while the potential across the crystal was changing from 0.03 volt to 0.6 volt, a factor of 20, the dynamic resistance (as measured by an alternating current bridge) remained relatively constant. The increase of resist-

ance from 380 to 400 ohms which occurred at the beginning of the run does not seem to be significant because the reverse effect did not appear. The measurements were made with a 1000-cycle bridge designed for high input impedance. To achieve adequate sensitivity the unbalance signal was amplified electronically. In order that the bridge be unaffected by the polarization voltage it was capacitatively coupled to the specimen. The polarizing current during these measurements was 20 microamperes.

A rough determination of the total resistance in the state of equilibrium polarization was made by means of the oscillograph connection

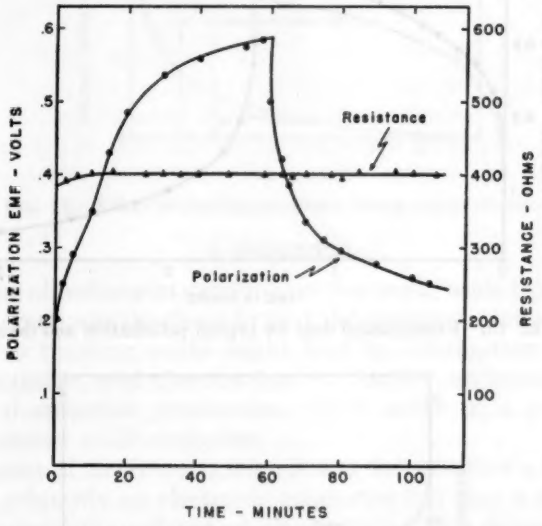

FIG. 12. Alternating-current resistance of ThO_2 specimen during development of polarization.

which was similar to that shown in Fig. 5, except that key K2 was normally closed and was opened momentarily after the sweep was initiated by K1. To avoid electrolysis this had to be done with very small currents and the gain of the oscilloscope amplifier was not sufficient to give good accuracy. It was determined, however, that such change of total resistance as may have occurred was less than 5 per cent.

6. *Decay of Polarization*

So far in this paper we have not discussed the manner in which the electromotive force falls back to zero when the polarizing current has been interrupted. In the first place, the precise course of this decay will depend upon the value of the resistance which the crystal looks into. There will be, however, a meaningful decay curve, if the crystal may be

regarded as looking into an infinite resistance. It was established that this was not far from being true in the case of a crystal in our furnace at 1300° C.; the leakage resistance involved was a number of megohms and the effect on the decay curve of shunting the specimen with a 1-megohm resistor was almost imperceptible. A typical pattern of growth and decay of polarization is given in Fig. 13. In general, the decay takes

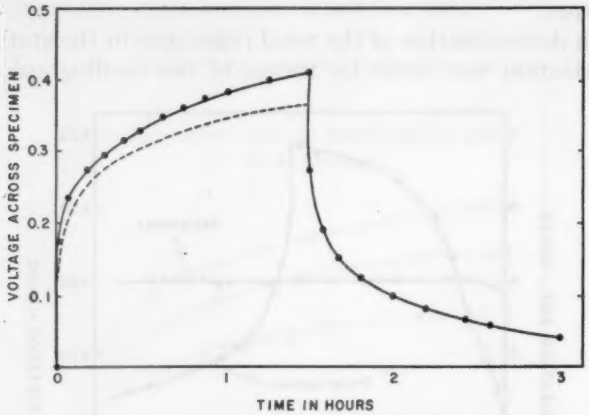

FIG. 13. Experimental data for typical polarization and decay.

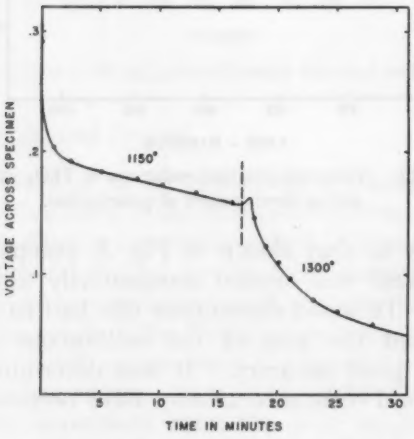

FIG. 14. Effect of temperature on decay.

place at a somewhat smaller rate than the growth. The dotted curve is the decay curve inverted for comparison of its functional form with that of the growth curve.

Figure 14 shows the increase in the rate of decay brought about by an increase in temperature of the specimen. In Fig. 15 is shown the

effect on the course of the decay curve of momentarily shorting the specimen. One sees that after the short is removed, the potential slowly rises again and resumes a course which is very similar to the original decay curve. The similarity, if not identity, of this phenomenon with that of so-called dielectric absorption or "soakage" is evident. It is highly probable that the basic mechanisms are closely related.

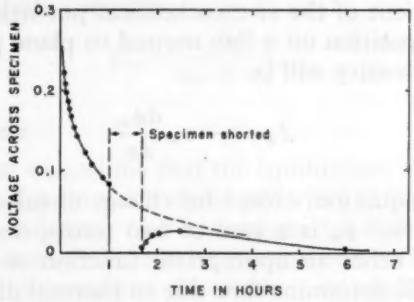

FIG. 15. Effect of shorting specimen during course of decay.

C. THEORETICAL

One of the objectives in carrying on this work, aside from the general scientific interest, was the thought that the interpretation of polarization phenomena in thorium oxide might lead to information regarding its ionic conductivity, and thereby lead to further understanding of the electrolytic destruction phenomena which occur to a greater or less extent in thorium oxide cathodes.

At the onset of the investigation it was thought that a thorium oxide crystal was primarily an electronic conductor but that a small percentage of ionic conduction existed which accounted for a degree of electrolysis and for the existence of polarization phenomena. However, if the considerations here given are correct, it would appear that the situation is the reverse of that cited; in a fresh, low-oxygen, thorium oxide crystal conduction seems to take place almost entirely by ions, the electronic component being only of the order of 1 per cent or less. Previous work relevant to the present problem has been done by, among others, Wagner (6), by Hebb (7), and by Bardeen, Brattain and Shockley (8). The main property which distinguishes the ions from the electrons, is that, although the electrons flow freely from the cathode into the crystal and from the crystal into the anode, there is, unless the critical decomposition potential be exceeded, no flow of ions across the boundary of the crystal to or from either electrode. It is this circumstance, which means that under the influence of an applied electric field the ions must form a non-uniform distribution, which results in the appearance of the polarization.

We now outline those considerations which enable one to deduce,

from the polarization curve, the transport numbers for electrons and ions respectively.

We assume we are dealing with conduction by electrons and by a single kind of positive ion. Again we let E_0, E_∞, E_1 be voltages as defined in Fig. 1*b*. J_+ and J_- will represent current densities carried by ions and electrons, respectively, and σ_+ and σ_-, the corresponding conductivities. The current density due to a given carrier will be proportional to the gradient of the electrochemical potential for that carrier. Letting x denote position on a line normal to plane parallel electrodes, the ionic current density will be

$$J_+ = -\sigma_+ \frac{d\phi_+}{dx}$$

with an identical equation, except for change of subscript, for the electrons. The quantity ϕ_+ is a sum of two terms, one the electrostatic potential and the other an appropriate function of ion concentration whose gradient will determine flow due to thermal diffusion.

Considering the mixed-conducting crystal with the metal electrodes in intimate contact, the question arises as to just what is measured when, while current is passing through the crystal, a potentiometer is connected to the electrodes. The reading of the potentiometer gives, of course, the difference of ordinary electrostatic potential between the electrodes. As regards the interior of the crystal, however, it may be shown that this measured voltage is equal to the difference of the *electrochemical potential* for electrons ($\Delta\phi_-$) across the crystal, this difference being considered between two points within the crystal, close to the electrode boundaries. With these preliminaries we now consider the state of the system under two conditions (*a*) when the current is first initiated and the voltage E_0 is observed and (*b*) after equilibrium has established itself and the voltage E_∞ is observed. It will be shown that the ratio E_0/E_∞ is, in the limit for small currents, equal to the fraction of current carried by electrons in the unpolarized specimen, that is, the transport number for electrons.

(*a*) *Initiation of the Current*

Assuming the current to be established instantaneously, the finite capacitance of the specimen results in a finite initial rate of rise. However, with a capacitance of the order of 1 $\mu\mu$f. and a specimen resistance of the order of 1000 ohms the time constant of this rise is 10^{-9} second. Therefore, since the observed rate of rise of polarization is of the order of several volts per second, it is evident that the capacitative effects are completely over before the polarization has had time to rise appreciably.

One may visualize, therefore, that, at the instant the current is initiated the voltage E_0 appears instantaneously and may be computed

from a total conductivity in which both ions and electrons move. The distributions of both kinds of carriers are uniform and hence no gradients of electrochemical potential exist, the flow of particles is caused entirely by the uniform electrostatic field, and the line integral of this field within the specimen is equal to the voltage E_0. Letting l represent the distance between electrodes the current will be equal to $(\sigma_- + \sigma_+) \times E_0/l$ for all values of x. Thus if the constant applied current density is J_0, we have at the initial instant

$$E_0 = \frac{J_0 l}{\sigma_- + \sigma_+}. \tag{1}$$

(*b*) *Equilibrium State*

In this treatment we assume that the equilibrium voltage is less than that required to maintain electrolysis and that this situation may be represented by the following two statements (*a*) that the positive ions encounter an impenetrable barrier at the cathode surface, and (*b*) that no positive ions are generated at the anode. At equilibrium, therefore, the positive ions assume a stable non-uniform distribution and all the current is carried by the electrons. Because, however, of the non-uniform ion distribution with its resulting space charge the electron distribution at equilibrium is also non-uniform. Hence, the current at any point is driven not only by the electric field, but also by such gradient in the electron concentration as may exist. Since, at equilibrium the charge distribution is unchanging, the electron current density must be constant throughout the specimen and this constant value will be the applied current density J_0.

We now assume that the J_0 is sufficiently small (allowed to approach zero, in theory) so that the electron density is at all points very little disturbed from its equilibrium value. Under these conditions the electronic conductivity σ_- may be taken as constant throughout and equal to its initial value as used in Eq. 1. We have, therefore, at all points in the crystal

$$J_0 = -\sigma_- \frac{d\phi_-}{dx} \tag{2}$$

which gives, after integration from $x = 0$ to $x = l$,

$$E_\infty = \phi_-(0) - \phi_-(l) = \frac{J_0 l}{\sigma_-}. \tag{3}$$

The transport number for the electrons is, therefore, given by

$$\frac{\sigma_-}{\sigma_- + \sigma_+} = \frac{E_0}{E_\infty}. \tag{4}$$

To calculate the transport number using this expression it must be remembered that the ratio E_0/E_∞ must be evaluated for E_∞ less than

that required for electrolysis. Referring to Fig. 2, if data are taken from the lowest observed point we have $E_\infty = 0.25$ volts and, taking the initial resistance from Fig. 8 as 400 ohms, $E_0 = 1.2 \times 10^{-3}$ volt. From this the transference number for the electrons is calculated to be $\frac{1}{2}$ per cent. Assuming that the curve approaches zero in the manner given in Fig. 4, and evaluating E_0/E_∞ for lower values of current, somewhat smaller values for the transference number are computed.

The validity of Eq. 3 depends upon the assumption that σ_- has essentially the same value in the polarized crystal as it had in the initial unpolarized state. The a-c. measurements plotted in Fig. 12 might be thought to bear upon this point. However, although they attest to the constancy of the total conductivity, they are insensitive to variations of the electronic component since it appears to be less than one per cent of the total. Similar considerations obtain regarding measurements of the drop in potential when, after equilibrium is established, the current is interrupted. Equality of the drop $E_\infty - E_1$ to the initial rise E_0 indicates constancy of the total conductivity, rather than that of the electronic component. Thus, at the present writing the validity of Eq. 3 rests upon the assumption of a non-varying electronic conductivity, an assumption which becomes increasingly justified as the total current is made small.[6]

As mentioned earlier, oscillographic observations have shown that the drop $E_\infty - E_1$ is equal to the initial rise E_0, the accuracy of this measurement being about ± 5 per cent. This invites the interpretation that the quantities $E_\infty - E_1$ and E_0 represent an "iR drop" in the specimen, the subsequent rise $E - E_0$ being a "polarization emf." Following this approach, the phenomena may be represented by a circuit as shown in Fig. 16, where R_i and R_e represent reciprocal conductivities

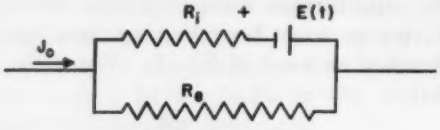

FIG. 16.

due to ions and electrons respectively and $E(t)$ is a back emf. which is allowed to increase in time in an *ad hoc* manner after initiation of the current. After equilibrium has been reached, $E(t)$ has become equal to E_∞. Upon interruption of the current the cell "discharges" through R_i and R_e and the measured voltage returns slowly to zero. The initial rise is obviously the iR drop due to the current through R_i and R_e in parallel and it may easily be shown that the fall of potential $E_\infty - E_1$

[6] Phenomena which might give rise to a change of contact resistance with polarization are not considered in the present treatment; flow of neutral centers is also assumed to be unimportant.

which occurs when the external circuit is opened is equal to the initial rise.

When one passes, however, from the equivalent circuit to attempts to set up an actual model in terms of motion of charged particles, a considerable degree of complexity is encountered and the subject has not as yet been placed on a satisfactory mathematical basis. As stated above, the situation is satisfactory with respect to the initial rise E_0; the difficulties arise regarding a rigorous explanation of the equality of $E_\infty - E_1$ and E_0.

This equality has been shown by J. F. Marshall[7] to obtain in the case where the constant conductivity is purely ionic, the particles being subject to electrical and diffusion forces. In this case, however, which again assumes no electrolysis, the voltage at constant current will increase indefinitely, will never reach an equilibrium value. In the present case where sufficient electronic conductivity exists to give an equilibrium emf. below the electrolysis value, the problem of explaining the equality in the presence of both types of carriers is still outstanding.

Acknowledgment

It is a pleasure to acknowledge the interest and support of Dr. W. F. G. Swann with respect to the present work. The progress of the studies was furthered by discussions with Dr. J. F. Marshall and Mr. D. L. Goldwater, the latter also assisting in some of the experimental work. Mr. Harry Bleecher rendered invaluable service of a technical character.

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Plotter Cuts Costs of Surveying and Mapping.—Costs of producing surveys and maps for a wide variety of industrial and engineering uses will be greatly reduced through use of a new aerial mapping instrument announced by the Bausch & Lomb Optical Co., Rochester, N. Y.

Known as the Balplex Plotter, it will produce maps from aerial photographs with contour intervals as small as 1 to 2 ft. When placed in the plotter, reduced transparencies made from the photographs produce a three-dimensional view of the ground such as might be seen by a giant whose eyes were hundreds of feet apart. The new instrument makes it possible to produce maps from these photos at a fraction of the cost and time of ground surveying.

One of the fastest growing fields in the nation, the science of aerial surveying is known as photogrammetry. The number of firms specializing in this work has expanded 20-fold in the past ten years as business and civic planners have discovered that aerial maps can be made in days rather than the months consumed in ground surveying.

The fast, economical system of mapping is now widely used to lay out housing developments, locate pipelines and highway construction, plan industrial expansions, lay out railroad extensions, study water flow, evaluate timber stands, and to estimate the amount of coal in huge storage piles.

Aerial mapping was not commercially feasible until ten years ago. Before that time, instruments to do the job sold in the range of $100,000 and were thus usually available only to government agencies.

In 1945, Bausch & Lomb introduced an aerial mapping instrument that sold for about $10,000. With this new lower-cost equipment, aerial mapping became a commercial possibility. This instrument was known as Multiplex Mapping Equipment and is today one of the leading instruments in the industry. The new Balplex instrument just introduced sells for approximately $4,250 and is expected to produce another major cut in aerial mapping costs.

The Balplex Plotter consists of a precision table over which are mounted two projectors. Photographs taken from high-flying airplanes are converted into transparencies and inserted into the projectors. When viewed with special stereo glasses, the two projected images produce a three-dimensional picture of the earth's surface. The operator then traces the ground image with a tracing table which records the surface of the ground at a particular level, producing a contour line. The table is then readjusted for each subsequent contour line.

Many design advancements, such as a unique light control, are incorporated in the Balplex to give the instrument greater accuracy and speed of operation. The projector design incorporates an ingenious ellipsoidal reflector developed by R. K. Bean of the U. S. Geological Survey. It was originally used in Twinplex Equipment, a device manufactured on special order by Bausch & Lomb for U.S.G.S.

The projection transparencies, known as diapositives, are 110 mm. square—a size which permits retention of all necessary details in the original 9 × 9 aerial photograph. Accurate maps with scales as large as 1 in. to 50 ft. can thus be produced. Maps can be made from photos taken from heights as low as 1000 ft. or as high as 35,000 ft. with the Balplex.

The Balplex projector frame can accommodate two additional projectors which sell at $2160 a pair. Balplex projectors also can be mounted on frames of the present Multiplex system.

ANALYSIS OF A DIFFERENTIAL MAGNETIC AMPLIFIER WITH FLUX RESET CONTROL *

BY

CHARLES A. BELSTERLING [1]

SUMMARY

This paper describes in detail the theoretical operation and mathematical analysis of a differential magnetic amplifier circuit operating on the flux reset control principle. Experimental results verify the theoretical operation and the usefulness of the derived gain and output range equations. With the results of this investigation, it is possible to make intelligent use of a simple, yet extremely versatile magnetic amplifier circuit.

INTRODUCTION

It has been recognized by leading authorities in the field of magnetic amplifier analysis (1, 2)[2] that there are several distinct methods of controlling magnetic amplifier cores. One of these is the flux reset principle which allows complete incremental control of the flux level in a core within $\frac{1}{2}$-cycle of the power supply frequency. This is made possible by decoupling the cores operating in one $\frac{1}{2}$ cycle from those in the other $\frac{1}{2}$ cycle and setting a flux difference into a pair with an a-c. voltage integral. In this way, the necessity for changing the average level of a current in an inductance (3) is eliminated and there is no inductive time constant. Circuits of this type can change output level 100 per cent within one cycle or less of the power supply frequency.

The circuit to be analyzed here is not new (4) and is one which the author has used with success simply on the basis of cut and try design. It is as simple and versatile as a magnetic amplifier can be and yet has all the desirable qualities. It contains the minimum number of components, has power and voltage gain, responds completely in one cycle of supply frequency to an a-c. or d-c. signal, is phase and polarity sensitive to its input signal and has zero output for zero input. In addition, it is worthwhile for considerable analysis because it is the basic form of a whole class of more complicated circuits operating in the same manner, including operational magnetic amplifiers. The results of this study will show the significant factors in the performance of the simplest circuit so that with normal engineering caution, the prediction of the behavior of more complicated circuits is immediately possible.

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* Submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

[1] The Franklin Institute Laboratories for Research and Development, The Franklin Institute, Philadelphia, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

DEFINITIONS

p = transform operator d/dt.

E_1 = supply voltage.

E_4 = control voltage.

E_0 = output voltage.

R_3, R_4, R_5, R_6, R_7 = linear resistances.

R_{1f}, R_{2f} = forward resistance of rectifier plus winding.

R_{1r}, R_{2r} = reverse resistance of rectifier plus winding.

L_1, L_2, L_3, L_4, M_{14}, M_{24}, M_{13}, M_{23} = unsaturated inductances of windings.

$\mu = \dfrac{d\phi}{dNi}$ slope of core characteristic.

θ = angles defined in an operating cycle.

$\Delta\Phi$ = flux difference in the cores.

K_v = voltage gain $\dfrac{\text{av. } E_0}{E_4}$.

K_p = power gain $K_v^2 \dfrac{R_4}{R_7}$.

CIRCUIT DESCRIPTION

The basic circuit for analysis is shown in Fig. 1 as a simple a-c. bridge in which one pair of legs contains fixed resistive elements and the other pair contains saturable inductive elements differentially controlled by auxiliary windings. Rectifiers in series with the cores allow

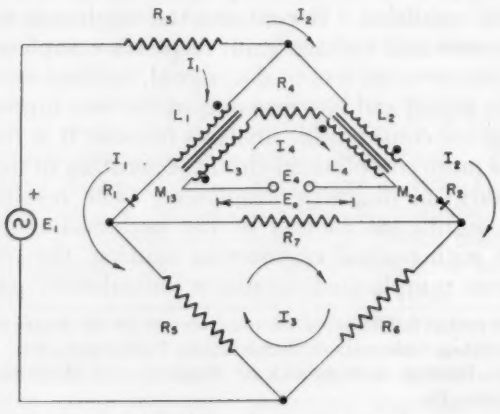
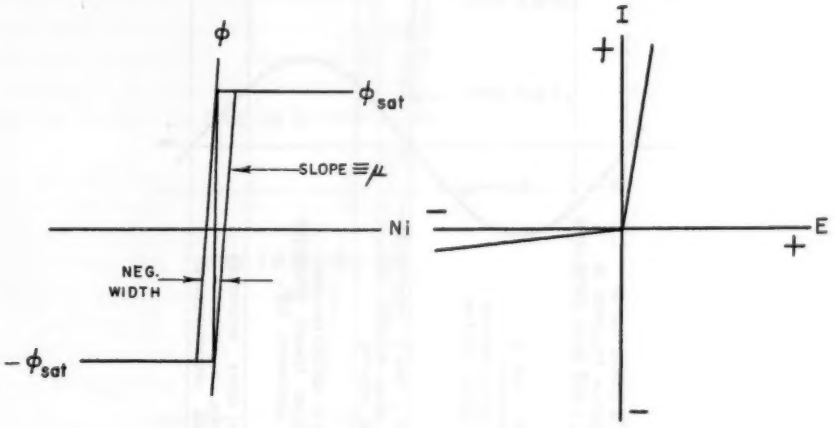


FIG. 1. The magnetic amplifier circuit.

conduction of load currents in the fixed resistors during one $\frac{1}{2}$ cycle. Then it is possible for a difference in voltage to develop across the bridge output terminals when the bridge is unbalanced.

Figure 1 is lettered with standard electrical symbols for linear elements and several modes of operation will be studied by recognizing changes from one condition to another of the non-linear elements. That is, the saturable cores will be assumed to have a flux versus magnetizing force loop as shown in Fig. 2*a* with 100 per cent residual flux but negligible width. In the limit this implies a single line with infinite slope through the origin. It follows that the incremental inductance of these wound cores will have a constant value in the unsaturated state and zero inductance when saturated. Similarly, the rectifiers will be treated as resistors of a low linear value in the forward direction and a high linear value in the reverse direction as shown in Fig. 2*b*. The symbols are all described in the preceding section on definitions.



a. Core *b*. Rectifier

FIG. 2. Assumed non-linear functions.

THEORY OF OPERATION

The unique operation of the circuit of Fig. 1 under the above assumptions can be described quite simply with the aid of intervals as defined in Fig. 3. Assume first that the circuit has been in balanced operation with zero control voltage for a cycle or more of the power supply frequency. As the power supply voltage comes down to zero, let us assume also that the cores are left at the positive saturation flux level. Now as the supply voltage goes negative, the rectifiers are high resistances but enough of the voltage is developed across the reactors that the flux levels drop through the unsaturated state to equal levels

at the end of the negative half-cycle (θ_2). The magnitude of the drop in flux levels is, by integration of Faraday's law

$$\int_{t_1}^{t_2} e\,dt = N\int_{\phi_1}^{\phi_2} d\phi$$

or

$$(\phi_2 - \phi_1) = \frac{1}{N}\int_{t_1}^{t_2} e\,dt$$

which states that the change in flux is proportional to the voltage integral developed across the reactor. Thus, the cores are reset in this $\frac{1}{2}$ cycle to a level which determines the firing angle of the core in the con-

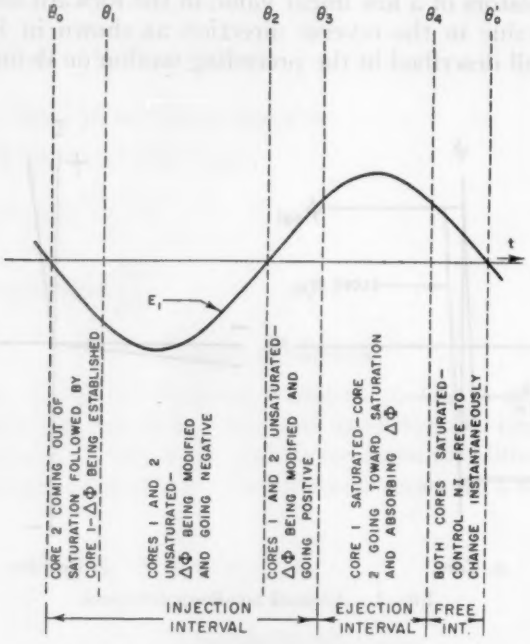

θ0
θ1
θ2
θ3
θ4
θ0'
t
E1
CORE 2 COMING OUT OF SATURATION FOLLOWED BY CORE 1-ΔΦ BEING ESTABLISHED
CORES 1 AND 2 UNSATURATED-ΔΦ BEING MODIFIED AND GOING NEGATIVE
CORES 1 AND 2 UNSATURATED-ΔΦ BEING MODIFIED AND GOING POSITIVE
CORE 1 SATURATED-CORE 2 GOING TOWARD SATURATION AND ABSORBING ΔΦ
BOTH CORES SATURATED-CONTROL N1 FREE TO CHANGE INSTANTANEOUSLY
INJECTION INTERVAL
EJECTION INTERVAL
FREE INT.

FIG. 3. Definition of angular intervals.

ducting $\frac{1}{2}$ cycle since when the power supply voltage goes positive the core can only absorb an integral of voltage equal to that of the reset voltage integral before it is again raised to the saturation flux level and "fires." Since the rectifiers are now forced to conduct forward current, they are very low resistance. At the beginning of the positive $\frac{1}{2}$ cycle a large proportion of the voltage is developed across the reactors until they fire at θ_3 and θ_4, after which most of the voltage for the rest of the cycle is applied to the fixed resistors R_6 and R_7. Since there is equal reset with no control voltage the cores will fire at corresponding angles

θ_3 and θ_4 and there is never any instantaneous voltage difference across R_7, and the circuit proceeds to the end of the positive $\frac{1}{2}$ cycle with the cores saturated and the fixed resistors R_5 and R_6 dropping equal voltages across them. This then is the quiescent condition when both cores fire at the same time to keep the bridge instantaneously balanced through a complete cycle.

Now, if a d-c. voltage E_4 is applied as a signal any time between θ_4 and θ_0', a current will flow instantaneously in the control winding since both cores are saturated (zero) inductances. Then when the supply voltage swings negative, different voltages are developed across the reactors and each core is reset to a different level because the reflected induced current in the control winding is seen differentially in the load

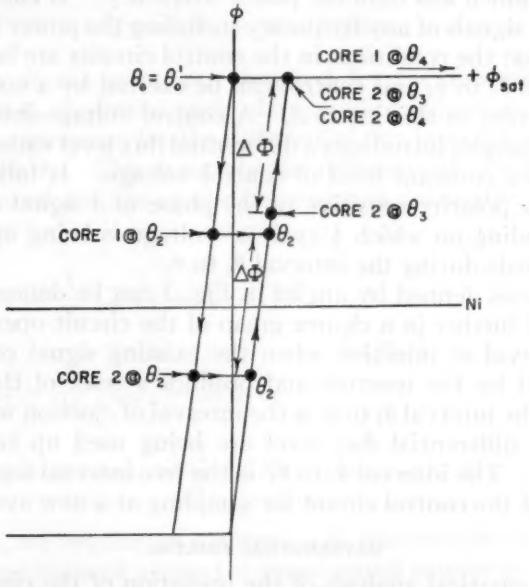


FIG. 4. Relation of core conditions to defined angles.

circuit reactances. The difference in the flux levels to which the cores are reset during θ_0 to θ_3 we have called $\Delta\Phi$, which is the differential quantity of flux. Now when the voltage swings positive, the core possessing the least amount of flux reset proceeds to saturation at θ_3, earlier than the quiescent firing angle. This core alone becomes a negligible inductance, unbalancing the bridge and permitting an instantaneous voltage difference to exist across R_7. This condition persists until θ_4 when the second core goes into saturation at an angle later than the quiescent firing angle. From θ_4 to θ_0' the bridge is again balanced with both cores being negligible inductances and equal currents in R_5 and R_6.

From the above description, it is evident that the output interval θ_3 to θ_4 is in some way a function of the differential flux $\Delta\Phi$ which is, in turn, a function of the control voltage E_4. The relation between these quantities is the object of this study. In addition, it follows that a new level of control current can be attained without inductive time lag in the interval θ_4 to θ_0' while both cores are in the saturated condition and there is no self or mutual inductance in these cores. Then, at θ_0' the cycle is repeated at a new level of reset independent of the previous cycle.

The angles of Fig. 3 can be directly related to conditions in the cores as shown in Fig. 4. The differential flux level of reset is roughly that difference in level in the two cores existing at θ_3.

It will be noted that the above description holds for control signals of d.c. and of much less than the power frequency. It can be extended to a-c. control signals of any frequency including the power frequency by recognizing that the conditions in the control circuits are being sampled in the interval θ_0 to θ_3 and control can be exerted by a control voltage integral occurring in this interval. A control voltage integral applied between these angles introduces a differential flux level without inductive lag as well as a constant level of control voltage. It follows that the output will be polarity sensitive to the phase of a signal of power frequency depending on which $\frac{1}{2}$ cycle of voltage is being applied at the control terminals during the interval θ_0 to θ_3.

The intervals defined by angles in Fig. 3 can be defined literally as follows to aid further in a clearer grasp of the circuit operation. θ_0 to θ_3 is the interval of injection when the existing signal conditions are being sampled by the reactors and produce a reset of the differential flux level. The interval θ_3 to θ_4 is the interval of ejection when the reset conditions of differential flux level are being used up to produce an output pulse. The interval θ_4 to θ_0' is the free interval for independent preparation of the control circuit for sampling at a new average level.

MATHEMATICAL ANALYSIS

The mathematical analysis of the operation of the circuit has been carried out by the application of operational methods. Initial conditions are neglected as it is recognized that at the end of every cycle both cores are always at the point of full saturation and the existence of transient conditions is not possible without any reactive elements in the circuit.

The four independent mesh equations of the system can be written for the general case as follows:

$$
\begin{aligned}
E_1 &= Z_{11}I_1 + Z_{12}I_2 + Z_{13}I_3 + Z_{14}I_4 \\
E_2 &= Z_{21}I_1 + Z_{22}I_2 + Z_{23}I_3 + Z_{24}I_4 \\
0 &= Z_{31}I_1 + Z_{32}I_2 + Z_{33}I_3 + 0 \\
E_4 &= Z_{41}I_1 + Z_{42}I_2 + 0 + Z_{44}I_4
\end{aligned}
$$

where

$$E_1 = E_2$$
$$Z_{11} = R_3 + pL_1 + R_1 + R_5$$
$$Z_{12} = Z_{21} = R_3$$
$$Z_{13} = Z_{31} = -R_5$$
$$Z_{14} = Z_{41} = pM_{14}$$
$$Z_{22} = R_3 + pL_2 + R_2 + R_6$$
$$Z_{23} = Z_{32} = R_6$$
$$Z_{24} = Z_{42} = -pM_{24}$$
$$Z_{33} = R_5 + R_6 + R_7$$
$$Z_{44} = R_4 + pL_3 + pL_4$$

Solutions of the array are required for the following conditions. Starting from θ_0, the initial angle of the applied voltage E_1, it is desirable to obtain an expression for the differential flux level $\Delta\Phi$ set in and held until the angle θ_3. This is simply the difference in the flux levels as a result of induced voltage on the two reactors during the reset intervals and simplifies to:

$$\phi_1 = \frac{1}{N_1}[L_1I_1 + M_{14}I_4]$$

$$N_1 = N_2$$

$$\phi_2 = \frac{1}{N_2}[L_2I_2 - M_{24}I_4]$$

$$\Delta\Phi_{\theta_0 \to \theta_3} = \phi_1 - \phi_2 = \frac{1}{N_1}[L_1I_1 - L_2I_2 + I_4(M_{14} + M_{24})].$$

Similarly, we require an expression in the ejection interval θ_3 to θ_4 for the voltage induced across the unsaturated reactor to determine the rate at which the injected differential flux is consumed. In the above equation L_1 and M_{14} go to zero and it simplifies to an expression for the behavior of $\Delta\Phi$ during the ejection interval:

$$\Delta\Phi_{\theta_3 \to \theta_4} = \frac{1}{N_2}[L_2I_2 - M_{24}I_4].$$

Of course, the third expression is that of the output voltage during the ejection interval θ_3 to θ_4 which is simply:

$$E_{0_{\theta_0 \to \theta_4}} = R_7I_3.$$

By solving the determinants of the array for the mesh currents (Appendix A), then letting the non-linear elements assume values cor-

responding to conditions in the respective intervals and substituting in these expressions, we have:

$$\Delta\Phi_{\theta_0\to\theta_3} = \frac{2\mu N_4 E_4}{pL_1R_4[Y_1 + Y_3 + 2Y_4]}$$

$$\Delta\Phi_{\theta_3\to\theta_4} = \frac{1}{pN_2}\left\{\frac{E_1R_4 - E_4\dfrac{N_4}{N_2}(2R_3 + R_{1f} + R_6)}{R_4(2R_3 + R_{1f} + R_6)[Y_1 + Y_2 + Y_4]}\right\}$$

$$E_{0_{\theta_3\to\theta_4}} = \frac{R_p}{R_{1f} + R_p}\left\{\frac{E_1R_4 - E_4\dfrac{N_4}{N_2}(2R_3 + R_{1f} + R_6)}{R_4(2R_3 + R_{1f} + R_6)[Y_1 + Y_2 + Y_4]}\right\},$$

where

$$R_p = \frac{R_6R_7}{2R_6 + R_7}$$

$$Y_1 = \frac{1}{|\omega L_1|}$$

$$Y_2 = \frac{R_3 + R_{1f} + R_6\left(\dfrac{R_6 + R_7}{2R_6 + R_7}\right)}{(2R_3 + R_{1f} + R_6)(R_{1f} + R_p)}$$

$$Y_3 = \frac{1}{R_{1r} + R_p}$$

$$Y_4 = \left(\frac{N_4}{N_1}\right)^2\frac{1}{R_4}.$$

Combining the latter two expressions in the interval θ_3 to θ_4 gives $\Delta\Phi$ as a function of E_0:

$$\Delta\Phi_{\theta_3\to\theta_4} = \left(\frac{R_{1f} + R_p}{pN_2R_p}\right)E_{0_{\theta_3\to\theta_4}}.$$

Now since both cores start from the saturation flux density at θ_0, go immediately into the unsaturated state and return to the same saturation density at θ_4, it follows that a differential flux level set into the cores during the injection period θ_0 to θ_3, must be absorbed by the one unsaturated core in the ejection interval θ_3 to θ_4, or simply the differential flux injected must be ejected to return to the same point. Then

$$\Delta\Phi_{\theta_0\to\theta_3} \equiv \Delta\Phi_{\theta_3\to\theta_4}.$$

Substituting the derived expressions in this identity gives the general relation between the output voltage E_0 and the control voltage E_4:

$$\left(\frac{E_0}{p}\right)_{\theta_3 \to \theta_4} = \frac{2\mu N_2 N_4 R_p}{L_1 R_4 (R_{1f} + R_p)[Y_1 + Y_3 + 2Y_4]} \left(\frac{E_4}{p}\right)_{\theta_0 \to \theta_3}.$$

Recognizing that $L_1 = \mu N_1^2$ and $N_1 = N_2$

$$\left(\frac{E_0}{p}\right)_{\theta_3 \to \theta_4} = \frac{2N_4 R_p}{N_1 R_4 (R_{1f} + R_p)[Y_1 + Y_3 + 2Y_4]} \left(\frac{E_4}{p}\right)_{\theta_0 \to \theta_3}.$$

Returning to the real time domain and dividing both sides by the angular period of the cycle gives

$$\frac{\int_{\theta_3}^{\theta_4} E_0 d\theta}{\theta_0' - \theta_0} = \frac{2N_4 R_p}{N_1 R_4 (R_{1f} + R_p)[Y_1 + Y_3 + 2Y_4]} \frac{\int_{\theta_0}^{\theta_3} E_4 d\theta}{\theta_1' - \theta_0}.$$

But

$$\frac{\int_{\theta_3}^{\theta_4} E_0 d\theta}{\theta_0' - \theta_0} = \text{av. } E_0$$

and

$$\frac{\int_{\theta_0}^{\theta_3} E_4 d\theta}{\theta_0' - \theta_0} \cong \frac{\theta_3 - \theta_0}{\theta_0' - \theta_0} \text{ av. } E_4.$$

Under the conditions of full control or maximum output

$$\theta_3 - \theta_0 \cong \tfrac{1}{2}(\theta_0' - \theta_0)$$

and

$$\frac{\theta_3 - \theta_0}{\theta_0' - \theta_0} \cong \frac{\text{av. } E_4}{2}.$$

Replacing these values in the gain expression results in a complete expression for the output voltage E_0 in terms of the average control voltage E_4 during reset,

$$\text{av. } E_0 = \frac{N_4 R_p E_4}{N_1 R_4 (R_{1f} + R_p)[Y_1 + Y_3 + 2Y_4]}.$$

In the design of a circuit, some of the above values are fixed by the available materials such as rectifier characteristics and reactor impedances while others are fixed by source impedances and load impedances. The free choice remaining to optimize the gain is the turns ratio $\frac{N_4}{N_1}$. If the gain expression is differentiated with respect to N_4 and the deriva-

tive set equal to zero, the result is an expression for the optimum turns ratio for maximum gain. The condition is

$$\text{opt.}\ \frac{N_4}{N_1} = \sqrt{\frac{R_4}{2}\left(\frac{1}{|\omega L_1|} + \frac{1}{R_{1r} + R_p}\right)}.$$

This expression is difficult to check experimentally because it is highly dependent on values of the non-linear elements which are difficult to define accurately in the reset interval. Now, if the optimum turns ratio is found either by the above expression or by experiment, the conditions can be substituted in the gain expression to give a reliable simplified equation for the optimized gain.

$$\text{opt.}\ \frac{\text{av. } E_0}{E_4} = \frac{N_1}{4N_4\left[1 + \dfrac{R_{1f}}{R_p}\right]}.$$

Now the non-linear elements are cancelled out except for R_{1f}. However, this is defined as the lumped forward resistance of the reactor leg of the bridge and includes the winding resistance which will usually swamp out the conduction resistance of most rectifiers. Then the expression for the optimized gain should be quite accurate once the optimum number of turns is determined.

It is also important in most cases to predict the available range of the output voltage before limiting occurs. The factors contributing to this limiting can be determined from the expression for output voltage E_0 previously found to be

$$E_{0_{\theta_3 \to \theta_4}} = \frac{R_p}{R_{1f} + R_p}\left\{\frac{E_1 R_4 - E_4 \dfrac{N_4}{N_2}(2R_3 + R_{1f} + R_6)}{R_4(2R_3 + R_{1f} + R_6)[Y_1 + Y_2 + Y_4]}\right\}.$$

The second term in the bracket is a measure of the current reflected from the control circuit into the load circuit during the conduction interval θ_3 to θ_4. It is not unreasonable to assume that this is quite small in most cases compared with the load current. Then

$$E_{0_{\theta_3 \to \theta_4}} \cong \frac{R_p}{(2R_3 + R_{1f} + R_6)(R_{1f} + R_p)[Y_1 + Y_2 + Y_4]} E_{1_{\theta_3 \to \theta_4}}.$$

Recognizing that the maximum average value of E_1 is the $\frac{1}{2}$ cycle average voltage of the power supply,

$$\text{max. av. } E_0 \cong \frac{R_p\, E_1/2.22}{(2R_3 + R_{1f} + R_6)(R_{1f} + R_p)[Y_1 + Y_2 + Y_4]}.$$

Now if the amplifier is optimized for maximum gain by proper adjustment of the turns ratio, the expression for maximum output voltage range with the turns ratio eliminated is:

$$\text{max. av. } E_0 \cong \frac{E_1/2.22}{1+\frac{R_{1f}}{R_p}+\frac{R_3}{R_p}+\frac{R_6}{R_7}+\left(1+\frac{R_{1f}}{R_p}\right)(2R_3+R_{1f}+R_6)\left(\frac{1.5}{|\omega L_1|}+\frac{1}{R_{1r}+R_p}\right)}.$$

EXPERIMENTAL AMPLIFIER AND TEST PROCEDURE

An experimental amplifier was constructed to check the above results of the mathematical analysis. The circuit is shown in Fig. 5 and

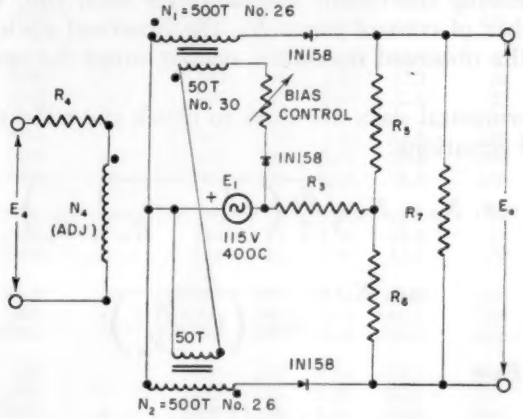


FIG. 5. Experimental amplifier circuit.

consists of two reactors of Deltamax 5 mil U laminations coupled through a common control winding. Numerous turns ratios were made available by tapping the control windings to allow for adjustment for optimum gain. A bias winding operating on the flux reset principle was also included which was designed to reflect a negligible admittance into the load circuit. The equivalent forward and reverse resistances of the rectifiers were estimated from manufacturer's data on the IN158 diffused junction germanium diodes. The impedance of the reactors was measured with a sinusoidal 400-cycle voltage applied which unfortunately is only a rough estimate of conditions existing in actual operation.

A comprehensive series of experimental runs was taken to determine the gain and the maximum range of the output voltage. Runs 1 through 5 were made by choosing a control winding resistance R_4 and varying the control turns N_4 to determine the particular value of N_4

which gives optimum gain with pure d-c. control voltage. This program was repeated in runs 6 through 10 with an a-c. control signal of 400 cycles in-phase with the power supply voltage.

Runs 11 through 16 were made under two conditions of optimum turns ratio varying only the line resistance R_3 with d-c. control. This plan was repeated in runs 17 through 22 with the a-c. control voltage. At this point, it was evident that either d-c. or a-c. control voltage will produce the same general effects and the remaining data are for the d-c. control voltage only.

Runs 23 through 28 were made under two conditions of optimum turns ratio for several values of bridge resistors R_5 and R_6 and runs 29 through 34 were made under the same two optimum conditions for several values of load resistance R_7. The results are recorded in the data sheets showing the circuit constants for each run, the observed optimum number of control turns N_4, the observed optimum voltage gain K_v, and the observed maximum output range for optimum turns ratio.

These experimental data are used to check the validity of the following derived equations:

$$\text{opt. } N_4 = N_1 \sqrt{\frac{R_4}{2}\left(\frac{1}{|\omega L_1|} + \frac{1}{R_{1r} + R_p}\right)}$$

$$\text{opt. } K_v = \frac{N_1}{4N_4\left(1 + \frac{R_{1f}}{R_p}\right)}$$

opt. max. av. $E_0 =$

$$\frac{E_1/2.22}{1+\frac{R_{1f}}{R_p}+\frac{R_3}{R_p}+\frac{R_6}{R_7}+\left(1+\frac{R_{1f}}{R_p}\right)(2R_3+R_{1f}+R_6)\left(\frac{1}{|\omega L_1|}+\frac{1}{R_{1r}+R_p}\right)}.$$

The values calculated from these equations are also recorded in Table I for comparison with the observed experimental values. Some sample calculations are given in Appendix B.

CONCLUSIONS

By observation of the experimental amplifier it was possible to verify the theoretical operation of the circuit as described in this report in every detail. The output waveform is a section of the sine wave of supply voltage as predicted from the defined interval θ_3 to θ_4 shown in Fig. 3. One of these pulses appears across R_7 every cycle and the width of the pulse is a function of the control voltage E_4. The polarity of the output pulse is controlled by the polarity or phase relation of the control voltage and the output polarity can switch completely from one direction to the opposite direction within one cycle of the power supply fre-

TABLE I.—*Data—Observed and Calculated.*

Constant values for all runs.

$R_{1f} \cong 25\Omega$ $N_1 = 500$ turns
$R_{1r} \cong 2.5 \times 10^6\Omega$ $\omega L_1 \cong 1.5 \times 10^4$
$E_1 = 115$ volts 400 cycles no signal $\theta_3 = \theta_4 = 90°$

Run Number	R_2	R_3	R_7	R_4	Observed Opt. N_4	Observed Opt. K_v	Observed Max. Av. E_0	Calculated Opt. N_4	Calculated Opt. K_v	Calculated Max. Av. E_0
1	0	1000	∞	100	25	6.00	44.8	28.8	4.90	45.9
2	0	1000	∞	1000	75	1.73	44.0	91.0	1.63	45.9
3	0	1000	∞	5000	180	0.72	44.5	208	0.68	45.9
4	0	1000	∞	10,000	220	0.51	43.0	288	0.55	45.9
5	0	1000	∞	47,000	550	0.24	—	624	0.24	45.9
6	0	1000	∞	100	25	4.50	47.0	28.8	4.90	45.9
7	0	1000	∞	1000	75	1.50	47.2	91.0	1.62	45.9
8	0	1000	∞	5000	180	0.70	46.9	208	0.68	45.9
9	0	1000	∞	10,000	210	0.44	46.3	288	0.58	45.9
10	0	1000	∞	47,000	500	0.23	—	624	0.26	45.9
11	0	1000	∞	100	25	6.00	44.8	29	4.90	45.9
12	150	1000	∞	100	25	6.00	37.2	29	4.90	39.5
13	300	1000	∞	100	25	6.00	32.0	29	4.90	34.6
14	0	1000	∞	10,000	200	0.52	44.0	288	0.60	45.9
15	150	1000	∞	10,000	200	0.53	36.8	288	0.60	39.5
16	300	1000	∞	10,000	200	0.54	31.8	288	0.60	34.6
17	0	1000	∞	100	25	5.30	46.3	29	4.90	45.9
18	150	1000	∞	100	25	5.30	42.0	29	4.90	39.5
19	300	1000	∞	100	25	5.40	37.1	29	4.90	34.6
20	0	1000	∞	10,000	200	0.52	44.5	288	0.60	45.9
21	150	1000	∞	10,000	200	0.53	41.7	288	0.60	39.5
22	300	1000	∞	10,000	200	0.54	36.9	288	0.60	34.6
23	0	250	∞	5000	150	0.86	45.5	203	0.76	45.9
24	0	1500	∞	5000	150	0.88	40.3	203	0.82	44.0
25	0	3000	∞	5000	150	0.91	33.4	203	0.83	39.4
26	0	250	∞	100	25	5.8	45.5	29	4.60	45.9
27	0	1500	∞	100	25	6.0	41.5	29	5.00	44.0
28	0	3000	∞	100	25	6.0	36.0	29	5.00	39.4
29	0	1000	250	100	25	3.10	8.40	3.84	4.10	9.70
30	0	1000	1000	100	25	6.00	21.3	3.60	4.70	23.6
31	0	1000	10,000	100	25	7.00	39.5	0.49	4.90	42.0
32	0	1000	250	5000	150	0.60	8.40	7.20	0.68	9.70
33	0	1000	1000	5000	150	0.80	21.0	3.20	0.78	23.6
34	0	1000	10,000	5000	150	0.82	38.9	0.33	0.81	42.0

quency. A photograph of actual conditions verifying these theoretical points is shown in Fig. 6.

Figure 7 is a typical plot of the experimental amplifier characteristics showing that there is a definite value of turns ratio which will result in maximum gain. This was predicted from the mathematical analysis and the expression for the optimum turns N_4 derived.

Figure 8 shows an actual curve of the characteristic of the experimental amplifier. It has a fairly linear gain up to a point where the

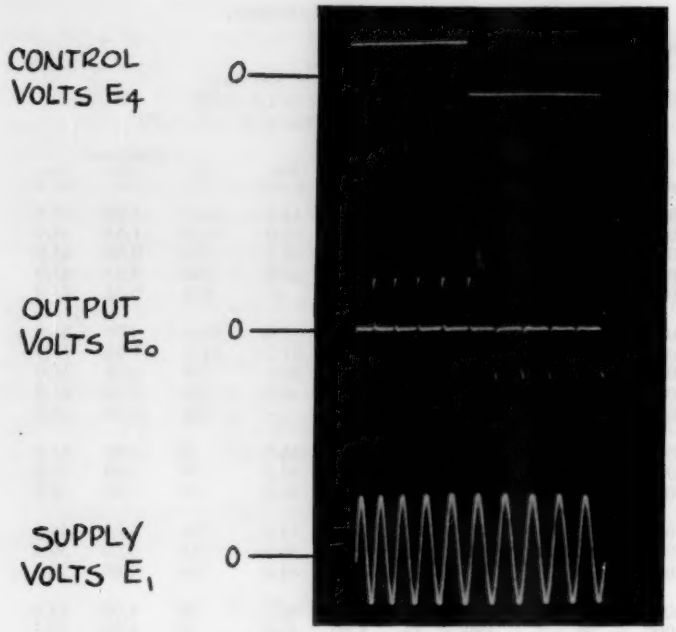


FIG. 6. Photograph of amplifier response to a step change of control voltage.

output voltage approaches a limiting asymptote. The gain equation has been derived and for the particular conditions is compared with the observed results in Fig. 8. The limiting output voltage has also been predicted in the analysis by the equation for maximum average E_0.

From a comparison of experimental and calculated values as shown in the data sheets of Table I, the following conclusions may be drawn.

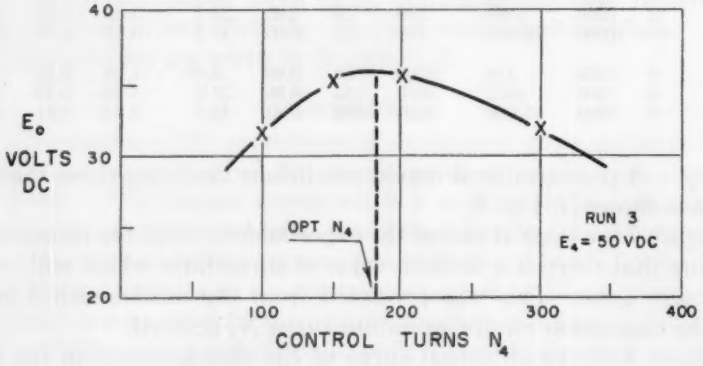


FIG. 7. Observed optimum turns N_4.

The expression for optimum control turns N_4 everywhere shows the proper trend in the proper increments. However, the calculations result in values for N_4 which are consistently high by approximately 20 per cent. Since the value for R_4 can be measured quite accurately and the reactor turns N_1 are definitely known, the errors lie in the values estimated for the non-linear admittances, $\frac{1}{|\omega L_1|}$ and $\frac{1}{R_{1r}+R_p}$. It is further evident that the sum of these should be less than estimated. Since R_{1r} is the minor contributor to the sum of the non-linear admit-

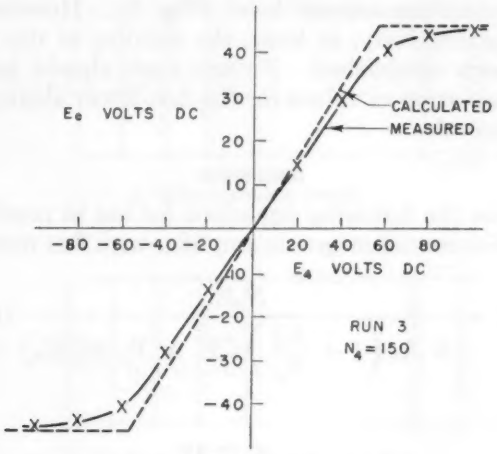


FIG. 8. Typical transfer characteristic.

tances, the writer believes that the estimated value of ωL_1 is too low. This is the magnetizing shunt reactance in the interval θ_0 to θ_3.

The second equation tested with the experimental data is the optimized gain equation. Here the expression for the optimum turns ratio was substituted into the general expression for gain to eliminate the non-linear quantities in an attempt to illustrate conclusively that better accuracy is obtained when the estimation of these quantities is not included. The comparison of observed and calculated values on this basis is generally much closer, usually within 10 per cent, and here error has been unavoidably introduced by not having control turns tapped at the exact optimum values. However, again the results show that the equations predict the effect on the optimized gain of all changes in circuit parameters in the correct directions and increments.

The remaining expression to be tested with the experimental data is that of the maximum range of output voltage. Here again the expression for optimized turns ratio was substituted to simplify the calculations, but this time to eliminate the turns ratio itself and let the

non-linear elements remain. These elements in this expression are minor contributors to the results, so less error is expected from this source than in the expression for optimum turns ratio. The correlation between most observed and calculated values is again approximately 10 per cent and everywhere the trends are well established and relatively correct.

Further errors could have developed easily in determining the values of observed optimum turns, gain, and maximum range because of the necessity of interpolating between measured values (Fig. 7), estimating values for the gain, which is not quite linear, and determining the actual value of the maximum output level (Fig. 8). However, the writer believes that qualitatively, at least, the validity of the results of this analysis has been established. Future work should include a more accurate determination of values for the non-linear elements during the appropriate intervals.

DISCUSSION

We now have the following equations for use in predicting the performance of a differential magnetic amplifier with flux reset control.

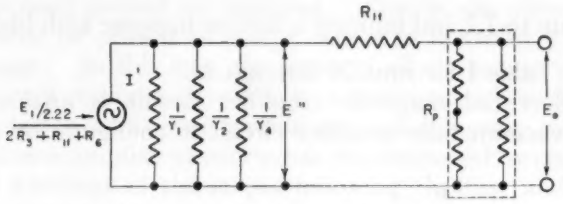
$$\text{av. } E_0 = \frac{N_4 E_4}{N_1 R_4 \left(1 + \frac{R_{1f}}{R_p}\right)[Y_1 + Y_3 + 2Y_4]} \text{ (Gain)}$$

$$\text{max. av.} E_0 = \frac{E_1/2.22}{(2R_3 + R_{1f} + R_6)\left(1 + \frac{R_{1f}}{R_p}\right)[Y_1 + Y_2 + Y_4]} \text{ (Range).}$$

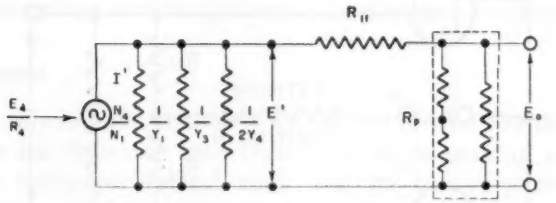
Equivalent circuits to show schematically the effect of circuit parameters are shown in Fig. 9. In addition to satisfying the condition for optimum control turns $N_4 = N_1\sqrt{\frac{R_4}{2}(Y_1 + Y_3)}$ the best choice of other circuit parameters is apparent. The gain equivalent circuit shows that the cores act as a current generator of magnitude $I' = \frac{E_4 N_4}{R_4 N_1}$. Its output current is applied across the parallel combination of impedances $\frac{1}{Y_1}$, $\frac{1}{Y_3}$ and $\frac{1}{2Y_4}$ reflected into the load circuit, to produce a generated voltage E'. This voltage is divided across R_{1f} and R_p, in series, to give the terminal voltage E_0. For maximum gain, the forward resistance of the rectifiers must be much less than $\frac{1}{2}$ the resistance network made up of the fixed bridge resistors R_5 and R_6, in parallel with the load resistor. In addition, the core reactance $1/Y_1$, the reverse rectifier resistance $1/Y_2$

and the reflected signal source resistance $1/Y_4$ must all be as high as possible.

For maximum range of output voltage the above conditions must also be satisfied, with the exception of optimum turns ratio. In addition, it is necessary to keep the ratios of the line resistance R_3 to the parallel resistance network R_p, and the bridge resistance R_6 to the load resistance R_7, as small as possible. The reflected conductance of the control circuit should be held to a minimum.



a. Gain equivalent circuit.



b. Maximum range equivalent circuit.

FIG. 9. Equivalent circuits of derived equations.

Some interesting observations can be made through further study of the gain equation. If all the above conditions are carried to the extreme to obtain maximum gain, the result would be

$$\text{max. } K_v \doteq \frac{N_1}{2N_4}$$

which would lead one to believe that reduction of the control turns toward zero would give an unlimited voltage gain. However, this conclusion is not valid and illustrates one of the weak points of this analysis, that is, the assumption of a core hysteresis loop with negligible width. Actually, some NI must be supplied by the control source to produce a change in the reset level. Then, in the case of real core characteristics, the above maximum gain equation would hold true only if the control source could supply an infinite amount of current. The error resulting from this condition is already becoming apparent in the data recorded in the experimental section of this investigation where the optimized value

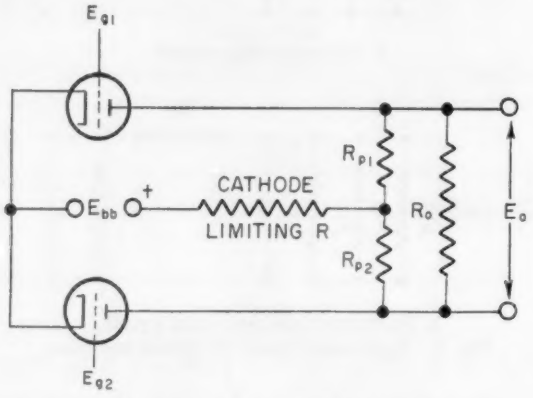
of gain has the least correlation for $N_4 = 25$ turns. It illustrates that even though the μ of the core has cancelled from the gain equation, it is important to minimize magnetizing current.

Values of power gain may also be of interest. If it is defined as

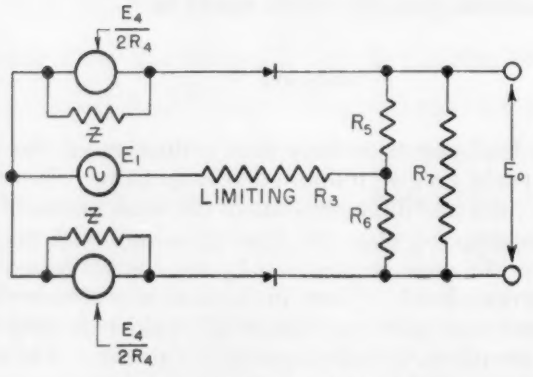
$$K_{p_c} \equiv \frac{E_0^2/R_7}{E_4^2/R_4} = K_v^2 \frac{R_4}{R_7}$$

then values calculated from the experimental data show a range of power gain up to 7.2 and indicate a further increase with higher $\frac{R_4}{R_7}$ ratio as shown in Table I for runs 29 through 34.

This differential magnetic amplifier circuit is analogous to the differential vacuum tube amplifier circuit in configuration as shown in



a. Vacuum tube differential circuit.



b. Magnetic differential circuit.

FIG. 10. Vacuum tube-magnetic amplifier analogy.

Fig. 10. Thus, the maximum gain will be available when the cores are biased Class A or at zero signal $\theta_3 = \theta_4 = 270°$. The instantaneous currents flowing in each half of the differential circuit after $\theta = 270°$ are limited only by the branch circuit resistance remaining and can become quite large when R_5 and R_6 are necessarily low. The solution to this problem is to add line resistance R_3 to limit these currents and as shown by the derived gain equation and the experimental results, the amplifier gain is not altered.

These differential amplifier circuits can be cascaded easily if the principles of reset control are observed. That is, the output $\frac{1}{2}$ cycle of one stage must be phased so that it occurs in the reset $\frac{1}{2}$ cycle of the following stage. In this way, the gains of all the stages will multiply and the over-all response time will be a maximum of one cycle for the first stage plus an additional $\frac{1}{2}$ cycle for each following stage. Power loss in resistance coupling networks can be eliminated by center-tapping the control windings of the stages following the first and connecting them as the fixed bridge resistances.

The circuit is also useful as an operational amplifier for the addition of isolated quantities and the performance of certain feedback functions.

Acknowledgment

The author wishes to acknowledge the aid of The Franklin Institute Laboratories for Research and Development in making available the facilities for the experimental work and for the preparation of this report.

APPENDIX A. SOLUTIONS OF THE ARRAY FOR THE MESH CURRENTS

The mesh equations (from Fig. 1) are:

$$\begin{aligned} E_1 &= Z_{11}I_1 + Z_{12}I_2 + Z_{13}I_3 + Z_{41}I_4 \\ E_2 &= Z_{21}I_1 + Z_{22}I_2 + Z_{23}I_3 + Z_{24}I_4 \\ 0 &= Z_{31}I_1 + Z_{32}I_2 + Z_{33}I_3 + 0 \\ E_4 &= Z_{41}I_1 + Z_{42}I_2 + 0 + Z_{44}I_4, \end{aligned}$$

where

$$\begin{aligned} E_1 &= E_2 \\ Z_{11} &= R_3 + pL_1 + R_1 + R_5 \\ Z_{12} &= Z_{21} = R_3 \\ Z_{13} &= Z_{31} = -R_5 \\ Z_{14} &= Z_{41} = pM_{14} \\ Z_{22} &= R_3 + pL_2 + R_2 + R_6 \\ Z_{23} &= Z_{32} = R_6 \\ Z_{24} &= Z_{42} = -pM_{24} \\ Z_{33} &= R_5 + R_6 + R_7 \\ Z_{44} &= R_4 + pL_3 + pL_4. \end{aligned}$$

Solution of the determinants of the array gives the following general equations for the mesh currents:

$$I_1 = \frac{E_1[Z_{44}(Z_{22}Z_{33} - Z_{23}^2) - Z_{33}Z_{24}^2]}{D}$$

$$- \frac{E_2[Z_{44}(Z_{12}Z_{33} - Z_{13}Z_{24}) - Z_{33}Z_{14}Z_{24}]}{D}$$

$$- \frac{E_4[Z_{33}(Z_{22}Z_{14} - Z_{12}Z_{24}) + Z_{23}(Z_{12}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$I_2 = - \frac{E_1[Z_{44}(Z_{12}Z_{33} - Z_{13}Z_{23}) - Z_{33}Z_{14}Z_{24}]}{D}$$

$$+ \frac{E_2[Z_{44}(Z_{11}Z_{33} - Z_{13}^2) - Z_{33}Z_{14}^2]}{D}$$

$$+ \frac{E_4[Z_{33}(Z_{12}Z_{14} - Z_{11}Z_{24}) + Z_{13}(Z_{13}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$I_3 = \frac{E_1[Z_{44}(Z_{12}Z_{23} - Z_{22}Z_{13}) + Z_{24}(Z_{13}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$- \frac{E_2[Z_{44}(Z_{11}Z_{23} - Z_{12}Z_{13}) + Z_{14}(Z_{13}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$- \frac{E_4[Z_{13}(Z_{12}Z_{24} - Z_{14}Z_{22}) + Z_{23}(Z_{12}Z_{14} - Z_{11}Z_{24})]}{D}$$

$$I_4 = \frac{E_1[Z_{33}(Z_{22}Z_{14} - Z_{12}Z_{24}) + Z_{23}(Z_{12}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$+ \frac{E_2[Z_{33}(Z_{12}Z_{14} - Z_{11}Z_{24}) + Z_{13}(Z_{13}Z_{24} - Z_{14}Z_{23})]}{D}$$

$$+ \frac{E_4[Z_{11}Z_{22}Z_{33} + 2Z_{12}Z_{13}Z_{23} - Z_{22}Z_{13}^2 - Z_{33}Z_{12}^2 - Z_{11}Z_{23}^2]}{D}$$

$$D = - Z_{14}[Z_{33}(Z_{22}Z_{14} - Z_{12}Z_{24}) + Z_{23}(Z_{12}Z_{24} - Z_{14}Z_{23})]$$

$$+ Z_{24}[Z_{33}(Z_{12}Z_{14} - Z_{11}Z_{24}) + Z_{13}(Z_{12}Z_{24} - Z_{14}Z_{21})]$$

$$+ Z_{44}[Z_{11}Z_{22}Z_{33} + 2Z_{12}Z_{13}Z_{23} - Z_{11}Z_{23}^2 - Z_{22}Z_{13}^2 - Z_{33}Z_{12}^2].$$

These expressions for the currents were substituted into the following equations and the impedances assigned for the appropriate intervals.

$$\Delta\Phi_{\theta_0 \to \theta_1} = \frac{1}{N_1}[L_1I_1 - L_2I_2 + I_4(M_{14} + M_{24})]$$

$$\Delta\Phi_{\theta_2 \to \theta_4} = \frac{1}{N_2}[L_2I_2 - M_{24}I_4]$$

$$E_{\theta_2 \to \theta_4} = R_7I_3.$$

APPENDIX B. SAMPLE CALCULATIONS

Run 3

$$(a)\quad \text{Opt. } N_4 = N_1\sqrt{\frac{R_4}{2}\left(\frac{1}{|\omega L_1|}+\frac{1}{R_{1r}+R_p}\right)}$$

$N_1 = 500$ turns

$\omega L_1 = 1.5 \times 10^4$ ohms

$R_{1r} = 2.5 \times 10^5$ ohms

$R_p = 1000$ ohms

$R_4 = 5000$ ohms

$$\text{opt. } N_4 = 500\sqrt{\frac{5000}{2}\left(\frac{1}{1.5\times 10^4}+\frac{1}{2.5\times 10^5+1000}\right)}$$

$$\text{opt. } N_4 = 500\sqrt{2500(0.7\times 10^{-4})}$$

opt. N_4 = 208 turns

$$(b)\quad \text{Opt. } K_r = \frac{N_1}{4N_4\left(1+\frac{R_{1f}}{R_p}\right)}$$

$N_4 = 180$ (observed opt.)

$R_{1f} = 25$ ohms.

$$\text{opt. } K_r = \frac{500}{4\times 180\left(1+\frac{25}{1000}\right)}$$

opt. K_r = 0.68

$$(c)\quad \text{Opt. max. av. } E_0 = \frac{E_1/2.22}{1+\frac{R_{1f}}{R_p}+\frac{R_5}{R_p}+\frac{R_6}{R_7}+\left(1+\frac{R_{1f}}{R_p}\right)(2R_2+R_4+R_6)\left(\frac{1.5}{|\omega L|}+\frac{1}{R_{1r}+R_p}\right)}$$

$E_1 = 115$ volts rms.

$$\text{opt. max. av. } E_0 = \frac{115/2.22}{1+\frac{25}{1000}+\left(1+\frac{25}{1000}\right)(25+1000)\left(\frac{1.5}{1.5+10^4}+\frac{1}{2.5+10^5}\right)}$$

opt. max. av. E_0 = 45.9 volts

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World Climate Warming Up.—A General Electric engineering consultant has suggested that the apparent "warming up" of the world's climate may be attributed to mankind "contaminating the Earth's atmosphere faster than Nature can clean it."

Dr. John G. Hutton of G.E.'s General Engineering Laboratory in Schenectady, N. Y., said the man-made increase in the belt of carbon dioxide encircling the Earth may be "having a greenhouse effect on our climate."

Trees and plant life take up carbon dioxide and discharge oxygen, thus tending to purify the atmosphere.

"However," he added, "when people chop down trees, bulldoze once-rural land for new suburbs, and build factories on former open fields, they lessen the amount of carbon dioxide Nature is cleaning from our air, as well as the oxygen Nature is putting into it.

"At the same time, people are increasing the air contamination by running more automobiles, trucks, trains, planes and ships, by building more factories and refineries and in other ways pouring carbon dioxide and other contaminants into the atmosphere."

Thus, he explained, the carbon dioxide content in the atmosphere is increasing, and this in turn may well have a "greenhouse" effect on the temperature of the air around us.

Dr. Hutton made the observations in a dinner address before members of the Cleveland Engineering Society. Speaking on "Fact and Fantasy," he also discounted the theory that the atomic test explosions caused weather changes resulting in floods, drought or temperature swings.

The G.E. consultant cited the Los Angeles smog problem as an illustration of the scientific theory that the world's population may be contributing more to atmospheric changes than any meteorological evolution or the nuclear explosions.

"Many people believe that the nuclear explosions have affected our weather patterns," Dr. Hutton said. "But how insignificant the energy of a hydrogen bomb explosion is when one considers that it would take exploding H-bombs at five-mile intervals over the face of the earth to equal the amount of radiation the Earth receives each day from the sun."

A summer thunderstorm, he said, has considerably more energy than any known H-bomb, yet it has no effect on the over-all weather pattern of the world.

"Nor does a hurricane, more violent than a thunderstorm and usually spread over a far wider area, have any more effect," he added. "The global weather pattern still prevails, with its winds, its high-pressure areas and its low-pressure areas."

Dr. Hutton noted that scientists throughout the world are preparing to study the "greenhouse" effect of carbon dioxide on climate to determine whether it might be causing a gradual warming of the Earth's air temperature. The study will be made as part of the observance of the International Geophysical Year in 1958, he said.

Slip Covers with Inside Piping.—Industry, taking a tip from busy homemakers, has come up with a novel idea of using "slip covers" to keep plant piping from corroding. The covers, which are made of oil-based vinyl plastic, are simply wrapped around ducts and conduits, closed with a plastic zipper, and sealed at the ends with vinyl tape and a brush-on coating. These plastic "zip covers" come in sizes to fit insulated pipe ranging from one-half inch to 33 inches in diameter and in lengths up to 100 feet, providing electrical insulation as well as protection against corrosion. Plastic jackets for factory piping represent one of the latest applications of petroleum products in the field of industry.

MEDAL DAY PROCEEDINGS AT THE FRANKLIN INSTITUTE

October 19, 1955

The annual reception, dinner, and presentation of awards, known as "Medal Day," took place at The Franklin Institute on Wednesday, October 19, 1955. The reception began at 6.30 P.M. and dinner was served at 7.10 P.M. Mr. S. Wyman Rolph, President of the Institute, presided at the dinner and presented the subsequent awards.

RECEPTION

The usual reception preceded the dinner and was attended by approximately 375 persons.

INVOCATION

The Reverend Philemon F. Sturges, Rector, St. Martin-in-the-Fields, Philadelphia, Pennsylvania, delivered the invocation.

* * *

Mr. Rolph extended thanks and appreciation to the members of the Hostess Committee of The Franklin Institute for their able assistance and for their kindness in providing the beautiful floral decorations. Dinner was then served.

TOAST

MR. ROLPH: "Ladies and gentlemen, will you rise so that we may continue our time-honored tradition—a toast to the great man in whose memory this institution was founded. May we ever continue to bring honor to his name."

* * *

MR. ROLPH (*continued*): "Now let us adjourn to the Lecture Hall on the floor below, where we will proceed with the medal-awarding ceremonies for which we have gathered tonight. There are stairs beyond the bronze gates on the far side of this Hall. There are elevators just beyond these pillars. We will continue our meeting in the Lecture Hall in ten minutes."

ADJOURNMENT TO LECTURE HALL

MR. ROLPH: "Distinguished guests, members of The Franklin Institute, Ladies and Gentlemen, I bid you welcome to the presentation of our Medal Awards for 1955. This marks the first Stated Monthly Meeting of the Institute for this season, and the first since May 18, 1955. The Minutes of the May meeting were published in the June issue of the JOURNAL OF THE FRANKLIN INSTITUTE. If there are no corrections or additions . . . I declare them approved as printed."

INTRODUCTION OF FORMER MEDALISTS

MR. ROLPH: "We are honored at these ceremonies by the presence of former recipients of medals of The Franklin Institute. Tonight we have a distinguished gathering. I call upon Mr. Ralph H. McClarren, Chairman of the Committee on Science and the Arts, who will introduce them to us—and let us now remember that the Science and Arts Committee is nearly one hundred and twenty-two years old and has quite some tradition behind it. As he is introduced, will each of our honored guests rise and remain standing until all names have been called. And will you, Ladies and Gentlemen, withhold your applause until all are standing? Mr. McClarren."

MR. MCCLARREN: "Former Medalists with us this evening are:

FORMER MEDALISTS ATTENDING MEDAL DAY—1955

Year	Medalist	City
	CRESSON (*Founded 1848*)	
1875	Merck & Co., Inc. represented by Charles A. Krieger	Rahway, New Jersey
1909	Underwood Corporation represented by David J. Crombie	New York, New York
1910	Automatic Electric Company represented by Percy G. Black	Chicago, Illinois
1934	Westinghouse Air Brake Company represented by G. W. Baughman	Pittsburgh, Pennsylvania
1952	H. Birchard Taylor	Ithan, Pennsylvania
	CERTIFICATE OF MERIT (*Founded 1882*)	
1908	General Electric Company represented by James J. FitzGibbons	Schenectady, New York
1921	Joseph S. Hepburn	Philadelphia, Pennsylvania
1939	E. Burke Wilford	Merion, Pennsylvania
1942	John J. Grebe	Midland, Michigan
1942	Walter Larkin	Norristown, Pennsylvania
1942	Goodyear Tire & Rubber Co. represented by Butler Doolittle	Akron, Ohio
1944	Western Union Telegraph Company represented by J. Z. Millar	New York, New York
1945	Walter J. Coppock	Moylan, Pennsylvania
1947	Peter F. Mulder	Shippensburg, Pennsylvania
	LONGSTRETH (*Founded 1890*)	
1904	Yawman & Erbe Manufacturing Company represented by James T. Brophy	Rochester, New York
1911	Joseph S. Hepburn (already standing)	
1921	L. H. Adams	Washington, D. C.
1922	Joseph F. Keller	New York, New York
1922	Remington Rand, Inc. represented by Paul E. Almquist	Stamford, Connecticut
1923	Harry S. Parks	Pottstown, Pennsylvania
1927	James F. Smathers	Poughkeepsie, New York
1928	Frank N. Speller	Pittsburgh, Pennsylvania
1948	Nicholas F. Arone	Upper Darby, Pennsylvania

POTTS (*Founded 1906*)

1939	N. K. Chaney	Philadelphia, Pennsylvania
1948	Clarence A. Lovell	Summit, New Jersey

LEVY (*Founded 1923*)

1945	Rupen Eksergian	Media, Pennsylvania
1946	George C. Southworth	Chatham, New Jersey

HENDERSON (*Founded 1924*)

1937	Rupen Eksergian (already standing)	
1954	C. L. Eksergian	Media, Pennsylvania

WETHERILL (*Founded 1925*)

1932	Monroe Calculating Machine Co. represented by George C. Chase	Orange, New Jersey
1934	E. Newton Harvey	Princeton, New Jersey
1941	Harold S. Black	Summit, New Jersey
1951	Reid Berry Gray	Baltimore, Maryland
1952	Albert J. Williams, Jr.	Philadelphia, Pennsylvania

BROWN (*Founded 1938*)

1954	Edmund Germer	Irvington, New Jersey

BALLANTINE (*Founded 1946*)

1947	George C. Southworth (already standing)	
1949	Sergei A. Schelkunoff	New York, New York
1952	Walter H. Brattain	Murray Hill, New Jersey
1953	David G. C. Luck	Collingswood, New Jersey

MR. ROLPH: "Gentlemen, we are honored to have you with us tonight. Thank you, Mr. McClarren."

"It is our custom at this time to ask Dr. Henry B. Allen, Executive Vice-President of the Institute, to report briefly on our activities during the foregoing year. Dr. Allen."

REPORT OF THE SECRETARY

"The Institute in 1955"

DR. ALLEN: "Mr. President, Ladies and Gentlemen. In gathering together a few of the highlights of the past year, I made 'usefulness' my yardstick—for this was the measure Benjamin Franklin used in regulating his own life.

"Our efforts to make our Museum attractive as well as instructive seem never-ending but are continually bearing fruit. Much attention has been given to the planning of new exhibits that will give our visitors a conception of important technical developments. At the same time, we are working toward a more attractive display of some of our old—but still timely—exhibits. The most extensive addition to our Museum is the Nickelodeon, a replica of the old-time motion picture house in which early moving pictures are shown. And also in our famous Locomotive Room, construction is underway of an extensive model railroad which will have some unique experimental features.

"Most of you, I am sure, are aware of the need for recruiting young

people into the technical and scientific fields. In this connection, an effort was made to display to high school students the opportunities for employment presented by the metallurgical industries. This was done in cooperation with the American Society for Metals, and met with such favorable response that we have been encouraged to make similar efforts with other industries. And also our 'work shops' for the young people have shown increasing interest.

"In the more technical and scientific fields, our own Laboratories for Research and Development continue to grow. With a technical staff of something over 230, our work for industry is about double that of the year before. Two new research sections were established this year: Engineering Psychology—a field of study that shows industry how best to fit its machines and processes to the abilities of its personnel; and another, Heat and Power—which shows promise, particularly in the field of nuclear power.

"Among our many Laboratory projects is one diagnosing the nature of smog and preparing the way for its abatement. Another project resulted in our finding a way to make adhesive bonded metal joints that are superior in many respects to riveted or welded joints. And grants from three Foundations are making it possible to develop surgical devices and aids for the blind, and to design endoscopic instruments—in every-day language, instruments carrying small but powerful lights for internal examinations. Another project resulted in the development of the Projection Magnifier, designed to help those whose sight deficiencies make ordinary printed matter impossible to read without the aid of powerful lenses. The Magnifier is now being produced by the American Optical Company, and one of the first models off its line is in our Laboratory exhibit outside the Lecture Hall for your inspection. I wish there were more time this evening to note in some detail the increased contributions of our Bartol Laboratories in nuclear physics, including cosmic rays.

"Our Library recently acquired microfilm copies of the hand-written patent specifications for the years 1790 to 1835—establishing the only record of this material in a Library outside of the Patent Office Library. And speaking of our Library, I should like to mention that our Librarian, Walter Pertuch, was honored at our Stated Meeting last November in recognition of his fifty years of service on the staff of the Institute.

"Our JOURNAL OF THE FRANKLIN INSTITUTE spent a busy year preparing the special January 1956 issue commemorating the 250th anniversary of Franklin's birth. Eighteen societies throughout the world to which Franklin belonged or founded will have papers in this issue—written in lay language and depicting advances in many fields of science and sociology since Franklin's day.

"Our endowment funds yield only a small percentage of income required to operate our regular activities. We are stepping up our

efforts to increase our annual gifts for operating expenses and to obtain additional funds for general and specific purposes. The gifts received in the past year, and others which we hope will come, will help us in our broad educational work, especially with junior and senior high school students.

"One special thing about 1955 is that we 'went over the top,' so to speak, when we had 7,002 members on our rolls as of September 30th. This is an all-time high for membership. Now our good Membership Committee is setting itself a new, higher goal.

"And one last highlight which just happened this afternoon: Dr. John S. Burlew has just been elected Director of The Franklin Institute.

"I close by paying tribute to the volunteer members of our Committee on Science and the Arts, for tonight's awards are the result of their conscientious and thorough investigations. One of the members of the Committee, who was to have been a sponsor this evening, was forced to decline—because he himself was awarded the Beal Medal of the American Gas Association in California just yesterday!—Thank you."

MR. ROLPH: "Thank you, Dr. Allen. (It was Mr. Edward Boyer who received the Beal Medal in California yesterday.)"

PRESENTATION OF AWARDS

MR. ROLPH: "In the Minutes of a meeting of the Board of Managers of The Franklin Institute held on March 18, 1953, there was a Resolution for the observance of the 250th anniversary of the birth of Benjamin Franklin. The Resolution starts out:

> Whereas, Benjamin Franklin was one of the first and greatest American pioneers in the promotion and communication of knowledge for the benefit of people in all countries, making significant contributions in the fields of pure and applied science, education, medicine, agriculture and the graphic arts, as well as domestic and international public service. . .

"and the Resolution goes on to say that we would 'cooperate with other Sponsors in the communication of these and other ideas to the citizens of all countries, for the purpose of helping toward a better world kinship and understanding among their people."

Tonight we have with us men of several nations who have shared, with all, the fruits of their investigations and labors. We hope that the international scope of our medal awards contributes to the free communication of ideas among citizens of all countries so that a better world kinship and a better understanding among all peoples will be possible.

"You may have noted that the Franklin Medal, our highest award, is missing from the program tonight. It will be presented on January 18, 1956, as part of our 250th anniversary celebration. This celebra-

tion, next year, will be marked by free communications among peoples of all languages, of all free nations, in commemoration of this great man who once said:

> God grant, that not only the Love of Liberty, but a thorough Knowledge of the Rights of Man, may pervade all the Nations of the Earth, so that a Philosopher may set his Foot anywhere on its Surface, and say, "This is my country."

"Could we today put that hope into more effective words?

"Now, let us proceed with the presentation of awards for 1955. Each Medalist is sponsored by the chairman of that sub-committee of the Committee on Science and the Arts which recommended him for the award. This sponsor will present the Medalist and read his citation."

PRESENTATION OF THE ELLIOTT CRESSON MEDAL
(Founded in 1848)

This Medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

(To F. Philip Bowden, Reader in Physical Chemistry, University of Cambridge, Cambridge, England.)

F. PHILIP BOWDEN

MR. ROLPH: "First, the Chair recognizes Dr. Frederic Palmer."

DR. PALMER: "Mr. President, I present, *in absentia*, F. Philip Bowden for an award.

"Dr. Bowden has contributed greatly to our understanding of phenomena that involve friction. For over two hundred years, the

chief cause of friction between two rubbing surfaces was thought to be the interlocking of their high spots. Most physicists, led by Bowden and his co-workers, now accept the theory that it is both plastic flow and welding at these high spots that causes friction. This means that the actual area of contact between two surfaces is small. It occurs only at the high spots and is independent of the degree of polish. This area is proportional to the load, since heavier loading causes greater plastic deformation. At local points of adhesion, very hot spots may develop that assist plastic flow and welding. Thus frictional resistance is due primarily to the shearing of welds at points of contact and secondarily to the ploughing of one material into the other.

"These and many other consequences of the weld theory of friction have been deduced from the ingenious and convincing experiments in Bowden's laboratory. It is hard to exaggerate their importance since we encounter friction at every turn.

"I present, *in absentia*, F. Philip Bowden, of Cambridge, England, as a candidate for an Elliott Cresson Medal, 'For his extensive experimental investigations of the friction between solid surfaces, investigations which combine simplicity and clarity, and for his findings regarding the detailed nature of the processes involved when one metal slides over another.' "

MR. ROLPH: "Thank you, Dr. Palmer."

MR. ROLPH (*continued*): "Mr. O'Donoghue, it is my pleasure, on behalf of The Franklin Institute of the State of Pennsylvania, in the absence of Dr. Bowden, to present to you, as Consul General of Great Britain, an Elliott Cresson Medal and the Certificate and Report which accompany it. Mr. O'Donoghue, will you see that they are forwarded to Dr. Bowden?"

Mr. O'Donoghue accepted the Medal, Certificate and Report.

PRESENTATION OF THE EDWARD LONGSTRETH MEDALS
(Founded in 1890)

This Medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes.

(To Robert W. Berriman, Emulsion Chemist, Kodak Limited, Wealdstone, Harrow, England; Cecil Waller, Chief Emulsion Chemist, Ilford Limited, Ilford, London, England; and Richard Y. Case, Assistant Manager & Chief Engineer, Power Transmission Division, United States Rubber Company, Philadelphia, Pennsylvania.)

MR. ROLPH: "The Chair recognizes Dr. Julian W. Hill."

DR. HILL: "Mr. President, I present Robert W. Berriman and, *in absentia*, Cecil Waller for awards.

"In 1867, it was observed that uranium salts fog photographic plates. This observation led, some thirty years later, to the discovery of radioactivity by Becquerel, who correctly interpreted the effect as resulting from an emanation, or radiation, from the uranium.

"Subsequent investigators showed that certain atomic particles emanating from radioactive elements leave individual tracks when they pass through the gelatin-silver halide emulsion of a photographic plate or film. These tracks are visible in the developed film as microscopic lines. Until recently, however, the study of atomic phenomena by the use of photographic film, despite this early promise, was disappointing. The films available responded only to particles that are, in the atomic sense, relatively slow and heavy, and results were erratic and not amenable to precise study. Advances in atomic physics for several decades depended on observations of atomic particles in other ways, for example, the Wilson cloud chamber and the Geiger counter.

ROBERT W. BERRIMAN

CECIL WALLER

"Within the past decade, the photographic film has at last become a precise and powerful tool for the observation of nuclear particles, and for this science is indebted to our medalists. Mr. Waller, after unsuccessful attempts by others, developed an emulsion of much increased sensitivity to heavy particles, such as alpha particles, and made quantitative studies possible. Dr. Berriman, working independently, developed emulsions sensitive to light, fast particles such as electrons.

"The work of these two men is, in a very real sense, complementary, and it is fitting that they should share in a joint award.

"I present Robert W. Berriman, of Harrow, Middlesex, England, and, *in absentia*, Cecil Waller, of London, England, as candidates for an Edward Longstreth Medal, each, 'In consideration of their contributions to the development of photographic emulsions especially

designed for the study of nuclear particles and events, which have made possible important new advances in this field, including the discovery of new nuclear particles and a better understanding of cosmic rays.' "

MR. ROLPH: "Thank you, Dr. Hill. Dr. Berriman, by the same authority, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it."

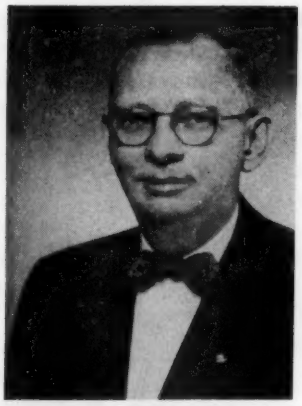
DR. BERRIMAN: "Thank you."

MR. ROLPH: "By that same authority, I present to Mr. Waller, *in absentia*, this Edward Longstreth Medal and the Certificate and Report which accompany it. Will you accept them for him, Dr. Berriman?"

DR. BERRIMAN: "Thank you."

MR. ROLPH: "The Chair recognizes Mr. Francis G. Tatnall."

MR. TATNALL: "Mr. President, I present Richard Y. Case for an award.



RICHARD Y. CASE

"Richard Case developed and tested, over a ten-year period, his 'Timing' Belt invention. This belt has rapidly taken its place in industry, replacing such older devices as gears, silent chain, roller chain, V- and flat belts, and is now standard equipment on a variety of mass-produced machines, including commercial sewing machines, business machines, machine tools, and power-driven hand tools.

"The advantages of this device are:

"Positive engagement of teeth with pulley grooves assures no slippage, creep, or power loss, and gives precision control of speed ratio; very small pulleys can be used without slippage, permitting short centers and high ratios. It is practically stretch-less because of steel cables, which also give greater pulling power, and the size of the belt can be varied for any horsepower requirements. The absence of

metal-to-metal contact eliminates lubrication; it is very light in weight; tests prove the belt drive quieter than precision gears running in an oil bath; and efficiency is maintained for low and high speeds up to 16,000 feet per minute. It does not depend on initial tension, resulting in high efficiency and low bearing pressure, often permitting lighter and cheaper bearings, and it is easily installed. The maintenance cost of the 'Timing' Belt is low because of elimination of stretch, lubrication, replacements, and power waste.

"I present Richard Y. Case, of Philadelphia, Pennsylvania, as a candidate for an Edward Longstreth Medal, 'In consideration of his invention of a successful "Timing" Belt, built upon a toothgrip design that makes positive engagement with axially cut grooved pulleys, thus producing a completely positive belt drive that does not depend upon frictional grip for the transmission of power and makes possible high precision timing between two or more shafts.' "

MR. ROLPH: "Thank you Mr. Tatnall. Mr. Case, by the same authority, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it."

MR. CASE: "Thank you."

DAVID ALBERT HUFFMAN

PRESENTATION OF THE LOUIS E. LEVY MEDAL
(Founded in 1923)

This Medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

(To David Albert Huffman, Assistant Professor of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.)

MR. ROLPH: "The Chair recognizes Dr. Joseph S. Hepburn."

DR. HEPBURN: "Mr. President, I present David Albert Huffman for an award.

"Dr. Huffman's paper, 'The Synthesis of Sequential Switching Circuits,' presents the results of a fundamental investigation, carried out at the Massachusetts Institute of Technology, into how modern 'thinking' machines can be designed. These machines include those used in the nation-wide telephone switching system, in automatic traffic control, in automation of factories, and in high-speed electronic computers. Some say that these machines, like people, have memories because the way they act depends not only on what is being done to them now but also on what has been done to them in the past. Since they can 'remember,' they can work with man to relieve him of much of the burden of performing routine mental labor.

"The main results of Dr. Huffman's work are to show how the design specifications for a thinking machine may be put into an exact mathematical language, and how the machine can be built from these specifications. The philosophy he develops is based on the idea that, no matter how complicated the required circuits are, they may be built from interconnections of simple devices, such as switches, vacuum tubes and transistors, which send out to, and receive from, the other devices only two kinds of signals. The research shows how many of these devices there must be and what instructions they must follow when they signal to each other.

"I present David Albert Huffman, of Cambridge, Massachusetts, as a candidate for the Louis E. Levy Medal, 'In recognition of his outstanding paper, "The Synthesis of Sequential Switching Circuits," appearing in the March and April, 1954, issues of the JOURNAL OF THE FRANKLIN INSTITUTE.'"

MR. ROLPH: "Thank you, Dr. Hepburn. Dr. Huffman, by the same authority, I present to you this Louis E. Levy Medal and the Certificate and Report which accompany it."

DR. HUFFMAN: "Thank you."

PRESENTATION OF THE GEORGE R. HENDERSON MEDAL
(Founded in 1924)

This medal is awarded for meritorious inventions or discoveries in the field of Railway Engineering.

(To Carleton K. Steins, Mechanical Engineer, The Pennsylvania Railroad Company, Philadelphia, Pennsylvania.)

MR. ROLPH: "The Chair recognizes Mr. C. D. Galloway."

MR. GALLOWAY: "Mr. President, I present Carleton K. Steins for an award.

"Modern railroading requires teamwork in research under the guidance of experienced engineers.

"Mr. Steins' distinguished accomplishments in this field are numerous and varied and have, in many ways, improved the efficient handling of both freight and passenger traffic in the United States. Some of his developments are as follows:

"His design of the type Q2 non-articulated freight locomotive, of which twenty-six were built, including his patented driving wheel 'slip control mechanism' and automatic steam valve;

"His patented freight load retaining apparatus for the interior of box cars to prevent damage to stacked materials;

"His design of a depressed center flat car to handle loads up to 500,000 pounds; and

"The development of post war high tensile steel passenger cars with unique ventilation, and air conditioning ducts as elements of the car structure.

CARLETON K. STEINS

"In 1954 Mr. Steins was appointed chairman of an engineering railroad group to study light weight, high speed, low cost passenger equipment both here and abroad.

"From this committee came several proposed trains, one of which was designed by Mr. Steins. This is now under construction and will be completed and in operation early next year.

"I present Carleton K. Steins, of Merion Station, Pennsylvania, as a candidate for the George R. Henderson Medal, 'In recognition of his numerous outstanding inventions contributing to the progress and efficiency of the railroad transportation systems, and his high engineering attainments in this same field.' "

MR. ROLPH: "Thank you, Mr. Galloway. Mr. Steins, by the same authority, I present to you this George R. Henderson Medal and the Certificate and Report which accompany it."

MR. STEINS: "Thank you."

PRESENTATION OF THE JOHN PRICE WETHERILL MEDALS
(Founded in 1925)

This Medal is awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known.

(To René A. Higonnet and Louis M. Moyroud, Research Engineers, Graphic Arts Research Foundation, Inc., Cambridge, Massachusetts; and Jacques Y. P. Séjournet, Directeur General, Comtoir Industriel d'Etirage & Profilage de Métaux, Paris, France.)

MR. ROLPH: "The Chair recognizes Mr. Ralph H. McClarren."

MR. MCCLARREN: "Mr. President, I present René A. Higonnet and Louis M. Moyroud for awards.

RENÉ A. HIGONNET

LOUIS M. MOYROUD

"These gentlemen have developed a new and radically different type of composing machine which marks the beginning of what might well be a new era in the printing and publishing industry. Their machine is called the 'Photon.' It does away with metal type and employs a master negative containing the equivalent of several thousand pounds of type characters on a small 8-inch diameter disc only $\frac{1}{8}$-inch thick.

"Their photographic type-composing machine contains the newest in electro-mechanical devices, computing circuits, and communication techniques to make a photographic negative from which, either by photo offset or engraving, a plate is made and a newspaper or a book printed. The machine remembers what the operator has typed, a line at a time, on a special electric typewriter keyboard. It also notes the size and kind of type selected. Then, automatically, it justifies the length of line and exposes the characters to the film while the operator,

in fact much more quickly than the operator, can type out the next line of copy.

"The Photon machine is a little larger than an office desk and offers the large printing house or the small city newspaper and printer a means of composition with flexibility and choice of characters hitherto available only to the special printing firm. It saves time and expense in doing most any kind of composition work.

"I present René A. Higonnet and Louis M. Moyroud, both of Cambridge, Massachusetts, as candidates for John Price Wetherill Medals, 'For their conception and development of the Photon Type-Composing Machine.' "

MR. ROLPH: "Thank you, Mr. McClarren. Mr. Higonnet, by the same authority, I present to you this John Price Wetherill Medal and the Certificate and Report which accompany it."

MR. HIGONNET: "Thank you."

MR. ROLPH: "And to you, Mr. Moyroud, by the same authority, I present this John Price Wetherill Medal and the Certificate and Report which accompany it."

MR. MOYROUD: "Thank you."

MR. ROLPH: "The Chair recognizes Dr. Nevin E. Funk."

DR. FUNK: "Mr. President, I present Jacques Yves Pierre Séjournet for an award.

JACQUES Y. P. SÉJOURNET

"The extrusion of metals is not new, both the hot and cold processes having been used for many years in the working of non-ferrous metals with marked success, but its application to the ferrous group was another matter.

"For technical reasons, only the hot process was attempted with ferrous metals and that not too successfully since the dies had very short lives. Sometimes a single pass would ruin a die and under other conditions even this single pass would not produce a commercial article.

"Lubrication was the problem. Graphite-grease mixtures in common use for heavy forging operations were first used. Many years passed before it was discovered that adding rock salt to the lubricant gave improved results. The problem was intensified with the advent of alloy steels requiring greater force to deform them.

"This was the situation in 1938 when Jacques Séjournet began research to discover a practical means of overcoming the difficulties of extruding steels. Experiments with various materials as lubricants were of little success in themselves but did prove, by the process of elimination, that a carbon free material of high melting point was required and finally led to the discovery that glass was a most useful lubricant, serving also as an insulator to protect the tools from the heat of the ingot, and was the basis of a practical economical method of extruding steel.

"I present Jacques Yves Pierre Séjournet, of Persan, France, as a candidate for a John Price Wetherill Medal, 'In consideration of his invention of the Ugine-Séjournet Extrusion Process for metals—stressing the ingenious utilization of glass as a lubricant and the effective method of its use.' "

MR. ROLPH: "Thank you, Dr. Funk. Mr. Séjournet, by the same authority, I present to you this John Price Wetherill Medal and the Certificate and Report which accompany it."

MR. SÉJOURNET: "Thank you."

CHARLES S. LEOPOLD

PRESENTATION OF THE FRANK P. BROWN MEDAL
(Founded in 1938)

This Medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

(To Charles S. Leopold, Consulting Engineer, Philadelphia, Pennsylvania.)

MR. ROLPH: "The Chair recognizes Mr. Joseph Gray Jackson."

MR. JACKSON: "Mr. President, I present Charles S. Leopold for an award.

"Mr. Leopold's incisive engineering approach has pervaded every aspect of the air conditioning field. He has applied air conditioning to great buildings, such as the Pentagon Building, the Fidelity-Philadelphia Trust Building, and the Philadelphia Convention Hall. He has been a great missionary in the development of panel cooling, preferring to remove the heat developed as near as possible to its source thereby avoiding the necessity of circulating great excess of cooling air. Mr. Leopold has made important contributions in the study of smoke elimination.

"I present Charles S. Leopold, of Philadelphia, Pennsylvania, as a candidate for the Frank P. Brown Medal, 'In consideration of his outstanding contribution to air conditioning, particularly in the research and development of air conditioning techniques and the application of air conditioning to a wide variety of important structures.' "

MR. ROLPH: "Thank you, Mr. Jackson. Mr. Leopold, by the same authority, I present to you this Frank P. Brown Medal and the Certificate and Report which accompany it."

MR. LEOPOLD: "Thank you."

PRESENTATION OF THE STUART BALLANTINE MEDAL
(Founded in 1946)

This Medal is to be awarded in recognition of outstanding achievement in the fields of Communication and Reconnaissance which employ electromagnetic radiation.

(To Claude Elwood Shannon, Research Mathematician, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.)

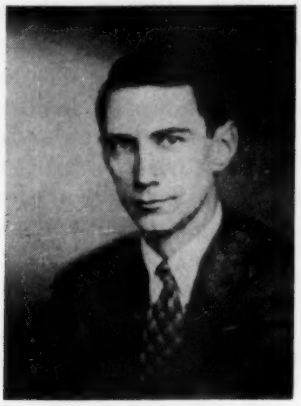
MR. ROLPH: "The Chair recognizes the final Sponsor of the evening, Mr. Lewis P. Tabor."

MR. TABOR: "Mr. President, I present Claude Elwood Shannon for an award.

"As the radio spectrum has become more and more crowded, and as new and more complex modulation systems have been developed for the purpose of transmitting data with greater reliability in the presence of noise, the need for a comprehensive mathematical method for the precise evaluation of proposed systems has become more and more acute. Unfortunately, for many years, the mathematical language used for describing the signal was not compatible with the mathematical language used to describe noise. Dr. Shannon has developed a mathematical procedure using the methods of statistics and probability to describe the signal, as well as the noise, in a common language.

"The effect of this development on the analysis of communications and data processing systems has been most impressive, as indicated by the very large numbers of important technical papers now being produced in which Dr. Shannon's methods are applied. New and interesting applications for Dr. Shannon's techniques are being found constantly, so that it seems probable that the effect of Dr. Shannon's work will be far-reaching indeed.

"I present Claude Elwood Shannon, of Chatham, New Jersey, as a candidate for the Stuart Ballantine Medal, 'In consideration of his recognition of communication as essentially a statistical process, his identification of the elements of communication systems with the appropriate statistical functions, and his welding of the powerful methods of mathematical statistics into a comprehensive theory of



CLAUDE ELWOOD SHANNON

communication which permits precise and rapid evaluation of proposed new communication systems, and points the way for significant new developments.' "

MR. ROLPH: "Thank you, Mr. Tabor. Dr. Shannon, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you this Stuart Ballantine Medal and the Certificate and Report which accompany it."

DR. SHANNON: "Thank you."

MR. ROLPH: "Ladies and Gentlemen, I wish it were possible for you to attend a meeting or two of the Committee on Science and the Arts, and particularly those of you who receive awards, for you would appreciate the fact that the Committee is made up of men of competence, dignity and integrity, and the members have a background of more than one hundred and twenty years to guide them in their deliberations.

"The work of these honored gentlemen may seem to be more or less removed from our daily lives. The electronic marvels of our age may seem too complex to contemplate. But our scientists are not recluses in their laboratories. Have you noticed the title of the address of the evening? It gives me great pleasure to present to you our Ballantine Medalist of this year who will speak to us of 'Game Playing Machines.' Dr. Claude Shannon."

ADDRESS BY CLAUDE ELWOOD SHANNON

(See page 447 of this JOURNAL for the text of Dr. Shannon's address.)

* * *

After Dr. Shannon had delivered his talk, Mr. Rolph conveyed to him the thanks of the Institute, dismissed the assembly with a cordial word and declared the meeting adjourned.

NUCLEAR ENERGY NEWS

CONTROLLED FUSION REACTION

At the opening of the Geneva "Atoms-for-Peace" conference in August Dr. Homi Bhabha, the conference president, made a prediction that the release of nuclear energy by controlled fusion of the nuclei of hydrogen or other light atoms would be accomplished in twenty years. At a news conference the next week Mr. Lewis L. Strauss made a cautious admission that the United States Atomic Energy Commission had been working on the problem. He promised to amplify that statement after his return to the United States.

The more extensive statement was made early in October. Mr. Strauss announced that the Commission is carrying on its major research effort in controlled thermonuclear reactions at Princeton University and at AEC laboratories operated by the University of California at Los Alamos, New Mexico, and at Livermore, California. In addition there are projects at Oak Ridge, Tennessee, and New York University. The over-all research program is known as PROJECT SHERWOOD.

Mr. Strauss said in part:

> It cannot be stressed too strongly that, based on what we now know, we are far from a solution of the problems of the controlled fusion reaction. Our work is in the research stage and many years of intensive effort may be required before the first prototype of an operating thermonuclear machine may be developed. We have every intention of attacking as vigorously as possible the remaining problems.

His statement pointed out that this process of energy release is believed to be similar to that which constitutes the source of the sun's energy. The *controlled* release of energy by the fusion reaction may offer significant potentialities for peacetime application, and the present research program within the AEC was instituted in the hope of developing these potentialities.

A corresponding announcement issued the same day by President Harold W. Dodds of Princeton University revealed that a classified project, known as PROJECT MATTERHORN, is being conducted at the James Forrestal Research Center of the University. The work at Princeton is directed by Dr. Lyman Spitzer, Jr., professor of astronomy. The theoretical aspects of this program were started in 1951, when Professor Spitzer approached the AEC with an idea for containing and controlling thermonuclear combustion at temperatures comparable to that of the sun itself.

Professor Spitzer issued the following statement through the Atomic Energy Commission:

> By far the greatest reserve of stored energy on earth is locked up in the nuclei of the hydrogen atoms present in the oceans. Deep inside the sun and the stars hydrogen nuclei combine to form helium nuclei, releasing vast energies. This combination, or fusion, of light nuclei is called "thermonuclear burning." The titanic energies released by thermonuclear burning have been unleashed in the hydrogen bomb.
>
> Thermonuclear burning occurs most readily with deuterium, a heavy isotope of hydrogen. Although only one deuterium nucleus is present in water for every 6400 nuclei of ordinary hydrogen, the total amount of deuterium available in the oceans is enormous. If the energy stored in these nuclei could be released in a controlled manner and used for generation of electrical power, a virtually inexhaustible supply of power would be available to mankind. Conservatively estimated, the deuterium in the ocean's waters is sufficient to provide many times the present rate of world energy consumption for more than a billion years.
>
> Thermonuclear burning occurs only at enormous temperatures, above a hundred million degrees Fahrenheit. Such temperatures have hitherto existed only at the centers of very hot stars or during the explosion of an atomic bomb. To convert the inexhaustible supply of energy in the earth's deuterium into useful power, we must achieve such temperatures in a gas confined within walls that remain relatively cool. We must control the thermonuclear reaction when it occurs. We must extract the energy released and use it to generate electricity. The scientific and technical difficulties to be surmounted are obviously formidable.

At Los Alamos Scientific Laboratory the first definitive experimental program got underway in January 1952, following earlier theoretical and experimental work going back to 1946, according to a statement issued by Dr. Norris E. Bradbury, Director of the Laboratory. He stressed the long-term nature of the project. Also he pointed out that although the release of thermonuclear energy might be associated in the public mind with the hazard of a tremendous explosion such as occurs in a hydrogen bomb, no such hazards seem to be present. The main problem seems likely to be that of getting enough thermonuclear energy back from the material, heated to more than one hundred million degrees, to repay the energy used to achieve and maintain this high temperature.

New York University's part in the project is carried on at the Institute of Mathematical Sciences, according to an announcement made by Chancellor Henry T. Heald. It is concerned with an attempt to understand the laws which govern the behavior of matter under the extreme conditions that exist during the fusion reaction. It has been found necessary to re-examine fundamental laws and to formulate new theories and develop new mathematical methods in order to obtain an insight into the mechanism of maintaining a stable configuration of heated material for a sufficiently long period of time.

The investigations at the Institute are primarily of a theoretical character and combine previously established theories in the fields of fluid mechanics and statistical mechanics. They are frequently aided

by extensive computations on a large scale high-speed digital computer which has been installed at the Institute by the AEC for its general program.

INCREASED FLUX OF M T R

The operating power level of the Materials Testing Reactor (MTR) at the National Reactor Testing Station in Idaho was increased one-third, the Atomic Energy Commission announced. This reactor was first placed in operation March 31, 1952.

Following periodic shutdown for refueling and changing experiments, the reactor was brought up to its usual operating level, 30,000 kilowatts of heat, in routine fashion. Then technicians of the operating contractor, Phillips Petroleum Company, Atomic Energy Division, gradually increased the power level, first to 35,000 kilowatts on September 23, then to 40,000 on September 26.

Observation of the reactor during and after the gradual increase verified preliminary calculations that such operation could be accomplished without presenting an increased safety hazard. No change in reactor design was required, the existing cooling system having been demonstrated to be capable of removing the additional heat generated. It would require 4000 tons of coal a month to produce the amount of heat generated by the MTR at the 40,000-kilowatt level. The amount of uranium-235 consumed by the reactor in maintaining this level is less than four pounds per month. The heat is dissipated by a cooling tower.

The advance in power level provides a corresponding increase in neutron flux, which already had been the world's most intense reactor neutron field. Preliminary calculations indicate that the reactor's usable thermal neutron flux has been raised from 3.5×10^{14} to 4.5×10^{14} neutrons per square centimeter per second.

The increase will enable the reactor to handle a greater experimental load by making more high flux space available and, in some cases, shortening the irradiation time. The reactor has been operating at capacity, particularly with respect to the experimental holes providing the highest flux.

The reactor is used both by AEC laboratories and private experimenters, with greatest emphasis being placed on experiments furthering the reactor development program, although its high flux enables it to produce radioactive isotopes of greater intensity than is possible elsewhere.

ENGINEERING TEST REACTOR

The Atomic Energy Commission announced on October 6 the signing of a letter contract with the Henry J. Kaiser Company, Kaiser Engineers Division, Oakland, California, for construction of the En-

gineering Test Reactor (ETR). It is to be located adjacent to the Materials Testing Reactor (MTR) at the National Reactor Testing Station in Idaho. Completion is scheduled for the spring of 1957.

The Kaiser Company was selected by the Idaho Operations Office of the AEC after consideration of proposals from 34 companies. The contract is for cost plus a fixed fee, with an estimated total cost of 15 million.

Conceptual design of the ETR had been made previously by the Atomic Energy Division of the Phillips Petroleum Company, which operates the MTR. Architect-engineering is to be done by the Kaiser Company, with nuclear design of the reactor and facilities within the tank being performed by the Atomic Power Equipment Department of the General Electric Company under sub-contract to Kaiser.

The reactor will operate at a power level of 175 megawatts of heat, which is more than four times the increased power level of the MTR (see preceding item). It will be light water moderated and cooled. The fuel will be enriched uranium fabricated in flat-plate assemblies similar to those used in the MTR.

The Engineering Test Reactor is being built to fill an urgent need for large experimental spaces in high neutron fields in which to perform tests furthering the nation's military and civilian nuclear power development programs. The reactor will have within the core a number of experimental holes capable of accepting reactor fuel elements and other components.

The holes will range up to nine inches square, and will extend completely through the core and reflector. Nearly all will be provided with tubes permitting connections to facilities such as pumps, heat exchangers, sampling equipment and clean-up systems outside the reactor tank. These will form loops in which tests may be conducted at temperatures, pressures, and other operating conditions similar to those which the materials being tested would meet in the reactor applications for which they are designed.

SMALL-SCALE NUCLEAR POWER PLANTS

The Atomic Energy Commission has invited proposals for the development, design, construction, and operation of small-scale nuclear power reactors to demonstrate the practical value of such units for commercial use. The electrical output is to be in one of the following ranges: 5 to 10, 10 to 20, and 20 to 40 megawatts. The closing date for receipt of proposals is February 1, 1956.

The invitation is the second one issued under the Power Demonstration Reactor Program that the AEC established in January 1955. (See this JOURNAL, Vol. 259, p. 531.) The aim of the program is to bring new resources into the development of engineering information on the performance of nuclear power reactors and to advance the time

when nuclear power becomes economically feasible. The first invitation for proposals, which was for larger plants, resulted in the submission of four proposals for power reactors, the combined electrical capacity of which would be 455 megawatts.

The AEC expects that development of small competitive nuclear power plants not only will benefit domestic users in certain areas, but also will help meet the requirements of foreign countries as well. The present invitation is extended to individual organizations and to groups of organizations representing private or publicly-owned utilities, equipment manufacturers, and others. The Commission will evaluate the proposals on a competitive basis. It may accept one or several or it may find that none is acceptable.

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

CERAMICS FOR PIEZOELECTRIC TRANSDUCERS

The National Bureau of Standards has developed several lead-oxide based piezoelectric ceramics that have excellent electromechanical properties and are stable over a wide temperature range. Some of these compositions, particularly in the lead titanate–lead zirconate system and the lead titanate–lead zirconate–lead oxide: tin oxide system, are expected to find considerable application as transducers for sensing elements in accelerometers, sound detectors, sonar, velocimeters, strain and pressure gages, and as drivers in ultrasonic devices. These materials can be expected to replace barium titanate in many commercial applications and to extend the use of ceramic transducers. The compositions were developed by B. Jaffe, R. S. Roth, and S. Marzullo of the Bureau's mineral products laboratories under the sponsorship of the Army's Office of Ordnance Research.

Piezoelectric ceramics are widely used as transducers for energy conversion between electrical signals and mechanical motion. Barium titanate has been used for many transducer applications, but these applications have been seriously limited because of its narrow temperature range—from 20° to 100° C. To overcome this limitation, and to improve the properties of ceramic transducers, the Bureau developed lead-oxide based ceramics of particular compositional ranges having a response that is uniform over a much wider temperature interval.

The lead-oxide based compositions have better electromechanical properties than the previously developed barium titanate ceramics because the proportions of their ingredients place them close to the boundary where morphotropic transformation—an abrupt change in the solid-solution phase—takes place. The Bureau has discovered that when the solid-solution phases of certain lead-oxide compositions are ferroelectric on both sides of the morphotropic boundary, the material yields ceramic transducers that have more desirable properties over a wider range of temperature than other compositions of similar crystalline structure.

Indications are that piezoelectric ceramics can be made only from ferroelectric crystalline materials. Barium titanate is an example of such a material. Its properties are enhanced at temperatures near those of polymorphic transformations below the Curie temperature. This effect is observed near 0° C., where the crystal form changes from one ferroelectric modification of the perovskite structure to another.

Compositional boundaries (morphotropic transformations) have been observed between ferroelectric phases of slightly differing structure. One example of morphotropism between ferroelectric phases in solid solution is found in the lead zirconate–lead titanate system. Experiments at NBS on this system[1] show that the room-temperature dielectric constant and the induced piezoelectric effects are enhanced as the composition approaches the phase boundary. For best piezoelectric and dielectric properties, the results indicate that compositional proximity to a morphotropic transformation appears to be more desirable than temperature proximity to a polymorphic transformation. As a consequence of these indications, experiments were continued on such solid-solution systems where morphotropic transformations can be found.

In the experiments on the new compositions, X-ray diffraction analyses were performed on matured ceramic specimens to determine the symmetry of the phases present in the solid solutions. The diffraction analyses were followed by measurement of the dielectric and piezoelectric properties. Among the compositions investigated were the lead titanate–lead zirconate, lead titanate–lead oxide: tin oxide, lead zirconate–lead oxide: tin oxide, and the lead titanate–lead hafnate binary systems; and the ternary systems, lead titanate–lead zirconate–lead oxide: tin oxide.[2] Although the mixture lead-oxide: tin oxide is not a compound, single-phase solid solutions can be formed with this material in combination with lead titanate or lead zirconate. Many variations in the proportions of the ingredients in these systems were examined. Morphotropic boundaries were found in a number of the systems. The dielectric and piezoelectric properties of all the compositions close to the morphotropic boundary were greatly enhanced.

One of the most useful compositions found in this investigation is that containing 45 per cent lead titanate: 55 per cent lead zirconate. Its Curie point is approximately 340° C., compared with a Curie temperature of 120° C. for barium titanate. The far higher Curie point of this new mixture greatly extends the useful temperature range of ceramic transducers. The lead titanate–lead zirconate has a radial coupling coefficient of greater than 0.3 at 275° C., and a piezoelectric voltage output coefficient (g_{31}) of 11.7×10^{-3} volt-meter per newton. The voltage coefficient is more than twice that of commercial barium titanate, while the piezoelectric charge output coefficients (d_{31}) of both materials are comparable. Because of the high voltage coefficient, this lead titanate–lead zirconate ceramic is particu-

[1] "Piezoelectric Properties of Lead Zirconate–Lead Titanate Solid-Solution Ceramics," by B. Jaffe, R. S. Roth, and S. Marzullo, *Jr. Applied Physics*, **25**, 6, 809–810(1954).

[2] "Properties of Piezoelectric Ceramics in the Solid-Solution Series Lead Titanate–Lead Zirconate–Lead Oxide: Tin Oxide and Lead Titanate–Lead Hafnate," by B. Jaffe, R. S. Roth and S. Marzullo, *J. of Research NBS.*

larly adaptable as a sensing element to convert mechanical motion or force to an electrical signal.

The addition of lead oxide: tin oxide to the lead titanate–lead zirconate provides another useful composition in the form $47\frac{1}{4}$ per cent lead titanate: $22\frac{3}{4}$ per cent lead zirconate: 30 per cent lead oxide: tin oxide. This composition has the highest piezoelectric charge output coefficient (d_{31}) of all the compositions examined—74×10^{-12} coulomb per newton. The high charge coefficient makes this material useful as a driver or generator of mechanical motion.

THE FRANKLIN INSTITUTE

MINUTES OF STATED MEETING

Wednesday, November 16, 1955

The Stated Monthly Meeting of The Franklin Institute was held on Wednesday, November 16, 1955, in the Lecture Hall. The meeting was called to order at 8:15 P.M. by the President, S. Wyman Rolph. There were approximately 200 members and guests present.

The President announced that the Minutes of the October Stated Meeting would be printed in the November JOURNAL and would be submitted for approval at the next Stated Meeting.

The Secretary reported that elections in membership recorded since September 30th resulted in a net gain in the following classes of membership: Active 6, Associate 16, Student 9, and individuals with Library privileges under Company memberships 1. Total membership as of October 31, 1955, was 7,031. He stated that now that a goal of 7000 members has been reached, a new goal of 10,000 has been set up.

The President then recognized Morton Gibbons-Neff, Chairman of the Membership Committee, who presented, *in absentia*, Mr. George R. Hall, of Madison, New Jersey, for recognition of his fifty years of continuous membership in The Franklin Institute. Mr. Hall, a graduate of the Hill School and of Yale University, was unable to be present because of doctor's orders. On behalf of Mr. Hall, the Secretary accepted a gold key and membership card from the President.

The President stated that this was the first of a series of annual endowed lectures named in honor of the late Philip C. Staples, former president of The Franklin Institute. The sum of $10,000 for this endowment was given to the Institute by a group of 89 friends of Mr. Staples and four companies. At the same time Mr. Staples was president of The Franklin Institute, he was president of the Bell Telephone Company of Pennsylvania. In choosing the speaker to deliver the first Staples Lecture, it seemed appropriate to try to get one who could talk on a subject very dear to the heart of Mr. Staples, namely, the continuing progress in the art of telephony being made by the Bell System. We were fortunate in that our invitation was accepted by a man pre-eminently qualified to speak on this subject—Dr. Mervin J. Kelly, President of Bell Telephone Laboratories.

Dr. Kelly's interesting and illustrated talk "Contributions of Research to Telephony—A Look at the Past and a Glance into the Future" was well received by the audience. It will be printed in the February issue of the JOURNAL.

The meeting adjourned at 9:20 P.M. with a rising vote of thanks to Dr. Kelly.

HENRY B. ALLEN,
Secretary

JOURNAL OF THE FRANKLIN INSTITUTE

The January JOURNAL will be devoted solely to 19 papers, written in honor of the 250th Anniversary of the birth of Benjamin Franklin. The authors are representatives of societies and organizations which Franklin either founded or of which he was a member. The titles of these papers, their authors and the societies represented are given below.

PANORAMA OF PROGRESS

INTRODUCTORY

A Program Poor Richard Would Have Loved.....C. L. Jordan
250th Anniversary Committee

B. Franklin and the Scientific Societies.....William E. Lingelbach
American Philosophical Society

SCIENCE (MAN AND MATTER)

Changing Concepts in Science.....Lord Adrian, O. M.
The Royal Society

States of Matter.....L. Jansen and A. Michels
Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte

The Coming of Age of the Atom.....Louis Leprince-Ringuet
Académie des Sciences

Benjamin Franklin and One Plutonic Year.....Harlow Shapley
American Academy of Arts and Sciences

Pioneers in Electrical Communications.....Eligio Perucca and Vittorio Gori
Accademia delle Scienze di Torino

SOCIOLOGY (MAN AND SOCIETY)

How Medicine Became a Science.....Sir Zachary Cope
The Medical Society of London

Franklin's Hospital, Our Hospital and the Hospital of the Future.....Sydney P. Clark
Pennsylvania Hospital

Franklin and the Unconquered Fields of Medicine.....Pierre Lépine
Académie nationale de Medécine

Benjamin Franklin, the Freemason.....William J. Paterson
Free and Accepted Masons

Franklin's Impetus to Education.....Gaylord P. Harnwell
University of Pennsylvania

ECONOMICS (MAN AND HIS WORK)

Food and the Future.....D. P. Cuthbertson
The Royal Society of Edinburgh

Franklin, the Businessman, First Great Apostle of Free and Competitive Economy on the American Scene.....Marion L. Musante
The Philadelphia Contributionship for the Insurance of Houses from Loss by Fire

Science and Agriculture.....Firman E. Bear
Philadelphia Society for Promoting Agriculture

INTERNATIONAL RELATIONS (MAN AND HIS IDEALS)

Some Aspects of Franklin's Life in England.....E. N. da C. Andrade
Royal Society of Arts

The Good Citizen of the World.....B. Hubert Cooper
The Society of the Sons of St. George of Philadelphia

The Simple and Honest Words.....John LaCerda
Poor Richard Club of Philadelphia

Our Political Crisis—and Faith.....The Rev. Ernest A. de Bordenave
Christ Church

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, November 9, 1955.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 9, 1955.

MR. RALPH H. MCCLARREN in the Chair.

The following report was presented for final action:

No. 3294: The Franklin Medal.

This report recommended the award of The Franklin Medal to Arne Tiselius, of Uppsala, Sweden, "In recognition of his brilliant investigations in biochemistry, particularly, his contributions to the knowledge of the proteins, and of his development of revolutionary new techniques and a powerful tool for use in the field of protein chemistry."

JOHN FRAZER,
Secretary to Committee

MEMBERSHIP

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November 16, 1955

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Frederick Rosengarten '11
John J. Schweikert '55
Henry Clapp Sherman '46
Haakon Styri '21

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 402 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays, and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

RECENT ADDITIONS

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NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

CHRISTMAS AT THE PLANETARIUM

The approach of the Christmas season always brings to mind the annual Planetarium demonstration which is designed to give fitting observance to an event symbolic of peace and goodwill. At a time when so many complaints are heard about the commercialization of the season, the Planetarium demonstration is a welcome revival of the feeling associated with the observance of an event that has both spiritual and historical significance.

"Something old, something new" can be applied to these occasions. What is old relates to the central story of the appearance in the skies of what was to be called later the Star of Bethlehem. It is not proposed to deny the likelihood that this phenomenon was miraculous in origin, but it can be shown that nature's immutable laws operated to produce an extraordinary spectacle as herald to the holy birth. Tracing the movement of the planets as they wheel on their appointed courses we find a singular grouping that must have been enough to strike simple people with awe.

Today, the majority of us are unconscious of the position of the heavenly bodies because the view of the night-sky is obscured by the glare of street lighting. But we should recall there was a time when the skies were under constant surveillance. The hour of the day and the seasons of the year were read in the skies. To people who kept a close watch on the heavens, the appearance of any unusual exposition provoked wonder. The appearance of a comet, as we know, was regarded as the portent of some great occurrence, and combinations of the planets, such as those that had never occurred in the memory of living man, were regarded as symbolic of coming events of extraordinary importance.

One of the great advantages of the Planetarium is its flexibility, which permits the instrument to travel through time and space to recapture the appearance of the skies in time past (or as they will be in time to come) and as seen from any part of the globe on which we live. This enables our demonstrators to arrange for a reproduction of the heavens as they were at a period before the Christian era had opened and as they were spread over the village of Bethlehem. By this means visitors to the Planetarium will be permitted to witness how the planets progressively drew together until they reached a conjunction such as no living man had ever seen, and which had

occurred only so far back in the past that, in the absence of adequate records, any similar appearance was probably unheard of. What was supposedly an unique sign in the night-sky would be a cause of immense wonder to the original beholders, and an earnest effort to associate it with one of the prophecies which people were waiting to find fulfilled.

The strange phenomenon has another significance. By piecing together fragments of recorded knowledge, and by working backward with astronomical calculations, the exact date of this natural phenomenon is found to have relation to the time of the Saviour's birth. The ambitions of Roman emperors or the zeal of their admirers had brought about a disruption in the methods of time measurement. By clarifying the confusion that this created we learn that our enumeration of the years *Anno Domini* is erratic.

However, this scientific interpretation does not occupy the Planetarium demonstration to the exclusion of the spiritual element. Year after year efforts have been made to enshroud the demonstration in an atmosphere of reverential joy that is characteristic of the reason why Christmas is faithfully observed throughout the Christian world. With each successive year the pageant has been improved from the experience gained in previous years, and the demonstration prepared for this year promises to be more popular than ever.

Having mentioned calendar confusion we might add a footnote respecting simplification. Visitors are recommended to see the World Calendar exhibit on the Ground Floor of the Museum. This revised calendar has been devised to remove many apparent inconsistencies and inconveniences inherent in our current calendar.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

TESTING OF ELECTRICALLY INITIATED EXPLOSIVE DEVICES

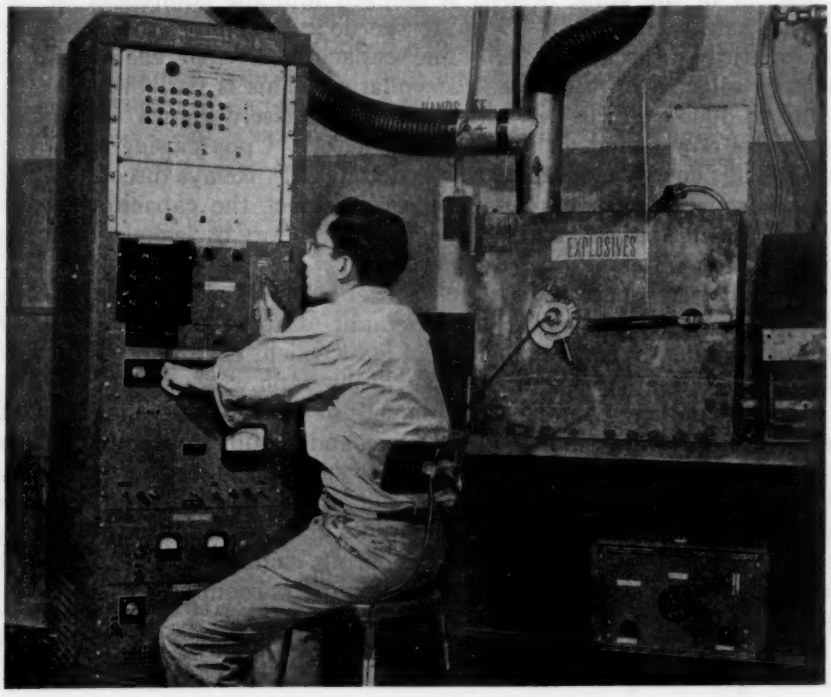
BY

CHARLES T. DAVEY

Engineers in the Engineering Physics Section of the Chemistry & Physics Division have designed a system for testing electric detonators. It is useful both in detonator research and as a production control test.

An electric detonator is a device loaded with a small quantity of sensitive explosive, which can be exploded by an electrical stimulus. The test system designed in the Laboratories provides means for measuring the electrical resistance of the detonator, controlling the amount of energy applied and measuring functioning time, that is, the time from application of the electrical pulse to explosion of the detonator.

The equipment is shown in the photograph. On the right is an



explosion chamber which affords the operators protection from noise, fumes, heat and blast as well as provides electrical and mechanical interlocks and other devices for safe, rapid handling and testing of various types of explosive devices. At left is the instrument rack; it contains an electronic counter-chronograph for measuring functioning time, a voltage attenuator and power supply to provide a precise amount of electrical energy (which is stored by a condenser prior to firing), a firing switch and circuit which operates quickly with very little loss of energy, and a Wheatstone bridge for measuring the electrical resistance of the detonator before it is tested.

A detonator is mounted with its connecting wires under spring-loaded clamps in the firing chamber. Its lead wires are twisted together at the free end as a safety measure. When the door of the chamber is closed and secured, the shorted leads are cut off and safety interlocks are engaged.

The Wheatstone bridge is then switched into the circuit and the resistance of the detonator is measured. The measuring current is limited to a low value to avoid changing the electrical characteristics of the detonator under test.

Polystyrene-film capacitors with high leakage resistance are used as reservoirs for the electrical energy that fires the detonator. A capacitor of the value desired is plugged into the equipment in the special safety chamber. (Opening the door to remove the capacitor automatically discharges it.) The capacitor is then charged to a voltage selected on the decade attenuator. This is variable from 0.1 volts to 1000 volts in 0.1 volt steps. A precisely known amount of energy is now stored on the firing capacitor. Upon closing the firing switch this energy is released to the detonator. Relays disconnect the charge source from the capacitor and connect the capacitor to the detonator in rapid sequence to avoid loss of energy by leakage from the charged condenser.

The voltage pulse applied to the detonator is also applied to the "start" circuit of the counter-chronograph. Explosion of the detonator is accompanied by a brilliant flash of light which, via a photomultiplier tube, supplies a "stop" pulse to the chronograph.

The explosion chamber is designed so that parts which receive severe damage are simple, inexpensive and readily replacable. It is lined with inch-thick sponge neoprene to suppress noise and trap flying fragments. Heat and fumes are quickly removed by an exhaust blower mounted above the chamber and special baffled air intake vents located at the bottom edges of the firing chamber. The electronic equipment is designed so that little training is required for safe, fool-proof operation.

The detonator evaluation system described above was developed under sponsorship of Picatinny Arsenal, Ordnance Corps, U. S. Army.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION
ELLICE McDONALD, M.D., FOUNDER WILLIAM G. BATT, D.Sc., DIRECTOR

EFFECT OF X-IRRADIATION *IN VITRO* ON KREBS 2 ASCITES TUMOR CELLS

BY

A. J. VIVOD, J. O. ELY, AND WILLIAM G. BATT

A study of the effect of X-irradiation *in vitro* on Krebs 2 ascites tumor cells was made. This was part of an investigation on the possibility of enhancing the effect of X-rays on tumors by X-ray-induced ultraviolet fluorescence of compounds previously accumulated in tumors. Irradiation *in vitro* was chosen in order to avoid the indirect effect on tumor growth caused by irradiation of the host animals.

The ascitic fluid containing the Krebs ascites tumor cells was obtained from Swiss mice bearing 6-day-old tumors. The ascitic fluid was diluted with Tyrode solution (pH 7.2) so that 0.2 ml. contained 14×10^6 tumor cells, the amount inoculated into each mouse. One portion of the dilute cell suspension was irradiated and the other non-irradiated portion was used for control purposes. The number of tumor cells was determined by counting in a haemocytometer. Only cells 12 microns or more in diameter were counted, since Patt and Blackford (1) found that there was a close correspondence between tumor cells estimated from stained preparations and large cells (greater than 12 microns) enumerated in a haemocytometer. X-irradiation of the suspended cells in small test tubes at the rate of 500 r per minute was made at room temperature with the Maximar 250 unit operated at 250 kvp. and 15 Ma. with inherent filtration equivalent to 3 mm. of aluminum.

At intervals of approximately 24 hr. after inoculation the number of tumor cells in groups of five mice was determined. Twenty cc. of Tyrode solution slightly acidified with citric acid was used to wash the cells from the peritoneal cavity of each mouse. The washings were pooled and tumor cell counts made.

Growth, that is, increase in the number of tumor cells, and alteration of the mitotic index were the criteria of the effect of the irradiation.

RESULTS

1. *Effect of 2000 r.*

The growth curve of the 2000 r X-irradiated tumor cells (Fig. 1) shows an initial drop at the 24-hr. post irradiation period followed by a rise. The curve then closely parallels at a lower level that of the nonirradiated cells. There were approximately one-third as many tumor cells per mouse of the irradiated cells at 48 hr. as there were in the mice receiving the nonirradiated cells. The mitotic index was

much greater during the period of observation than in the controls (Fig. 2). The irradiated cells were much enlarged during the first 3 days after irradiation and many of the mitotic figures were abnormal, showing fragmented chromosomes, lagging chromosomes and chromo-

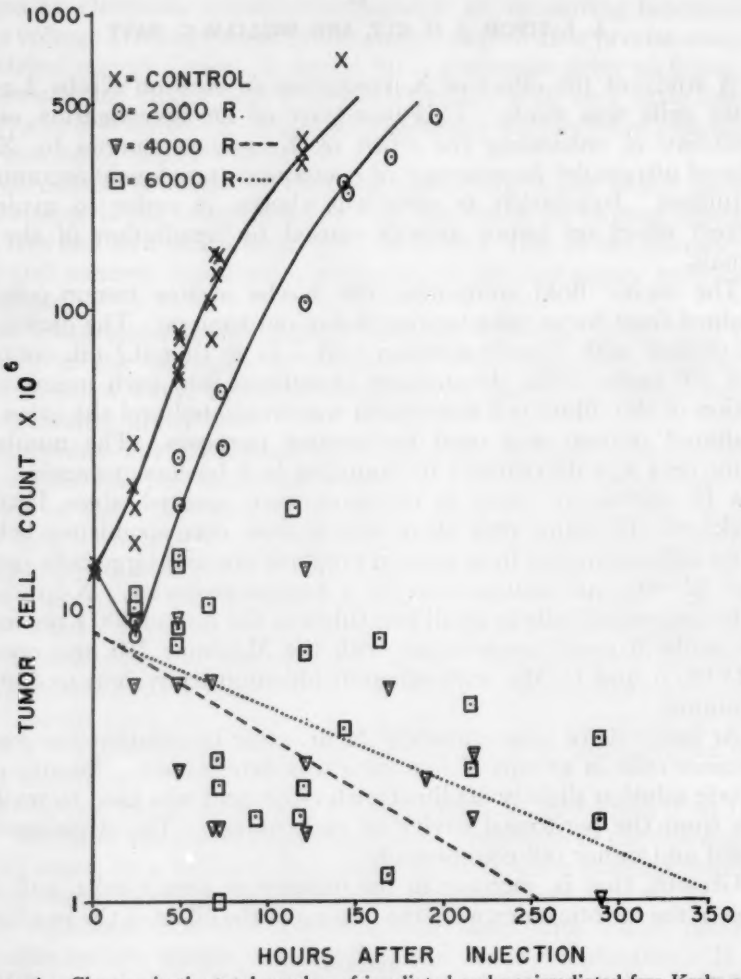


FIG. 1. Changes in the total number of irradiated and nonirradiated free Krebs ascites tumor cells in the entire peritoneal fluid of the mouse. (Least squares lines are shown to represent the decrease in growth of the 4000 r and 6000 r irradiated cells.)

some bridges. After 3 days the surviving cells became smaller with fewer abnormal mitotic figures.

2. Effect of 4000 r.

After 4000 r the number of tumor cells per mouse became progressively smaller with time. All tumor cells apparently were rendered

incapable of reproduction of a viable line of cells although cells in mitosis persisted 3 or 4 days. Irradiated tumor cells were extremely large and all mitotic figures were abnormal. Twenty-four hours after irradiation the mitotic index was approximately one-third of that of the nonirradiated cells; 48 hr. after irradiation it was greater. Then

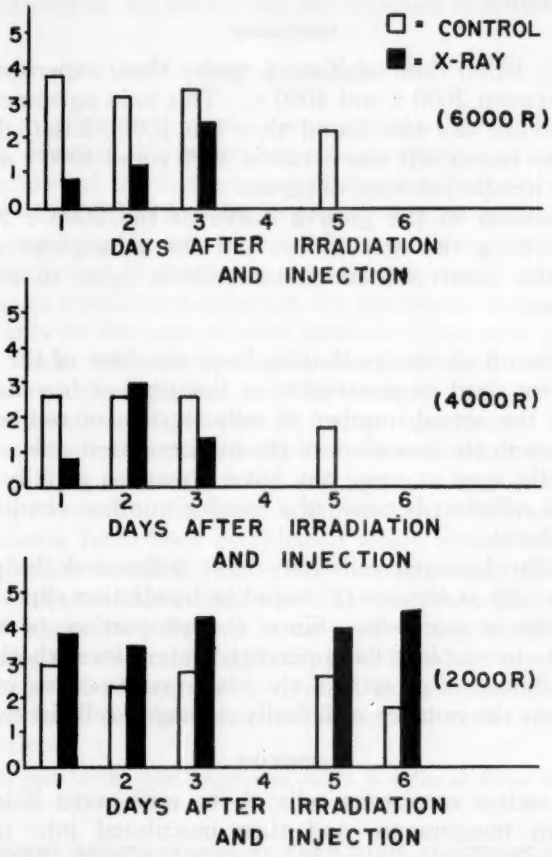


FIG. 2. Mitotic index of irradiated and nonirradiated Krebs ascites tumor cells.

the index decreased until at the end of 4 days it was 0. Since the number of tumor cells progressively decreased the abnormal mitoses must have been abortive.

At 1, 2, and 3-day intervals after irradiation, about 2 per cent of the cells stained with eosin immediately after removal from the mice, an indication that tumor cells were dying faster than they were disappearing from the peritoneal cavity. None of the cells in the controls stained during this period.

3. Effect of 6000 r.

The effect of 6000 r appears to be similar to that of 4000 r except that there was a lag in the appearance of the greatest number of mitotic figures. The similarity apparently indicates that 4000 r inflicts a maximum of damage and that the addition of 2000 r shows little further effect.

DISCUSSION

The 100% lethal dose of X-rays, under these experimental conditions, was between 2000 r and 4000 r. This is in agreement with the results of Révész (2) who found that the 100% lethal dose for the Ehrlich ascites tumor cell was between 3000 r and 4000 r although the conditions of irradiation were different.

The depression in the growth curve of the 2000 r X-irradiated tumor cells during the first 24 hr. and the subsequent rise parallel to that of the nonirradiated tumor cells is open to at least two interpretations.

(1) As a result of the irradiation large numbers of the tumor cells may have been dead or non-viable at the time of inoculation of the mice so that the actual number of cells capable of reproduction was much less than in the inoculum of the nonirradiated cells. The viable implanted cells may or may not have grown as rapidly as did the nonirradiated cells but because of a smaller number, the growth curve is at a lower level.

(2) Lethally damaged cells may have influenced the growth rate of the viable cells as Révész (2) found in irradiation experiments with Ehrlich ascites tumor cells. Since the proportion of the lethally damaged cells to viable cells apparently determines whether a stimulation or inhibition of growth of the viable cells occurs, one can only speculate as to the number of lethally damaged cells in the inoculum.

SUMMARY

Krebs 2 ascites carcinoma cells of the mice were X-irradiated *in vitro* at room temperature and then inoculated into mice. Their growth and mitosis were studied. Irradiation with 2000 r caused a marked depression in the growth curve in the first 24 hr., after which the growth curve paralleled that of the nonirradiated cells. The mitotic index increased and there were many abnormal mitoses. Irradiation with 4000 r and 6000 r completely inhibited growth of the tumor cells and all mitotic figures were abnormal. The total lethal dose was found to be somewhere between 2000 r and 4000 r.

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(1) H. M. PATT AND M. E. BLACKFORD, *Cancer Research*, **14**, 391 (1954).
(2) L. RÉVÉSZ, *J. Nat. Cancer Inst.*, **15**, 1691 (1955).

NOTES FROM THE BARTOL RESEARCH FOUNDATION

W. F. G. SWANN, DIRECTOR

ELECTROMAGNETIC ACCELERATING MECHANISMS FOR COSMIC RAYS *

BY

W. F. G. SWANN

In a report presented at the International Cosmic Ray Congress, Guanajuato, Mexico, the writer has taken occasion to summarize the essential features of the accelerating mechanism first proposed by him in 1933, and extended in a series of papers of later dates.

Further extension is now realized by a proof to the effect that if E is the electric and H the magnetic field, the condition, $|E| > |H|$ at all points as a sufficient criterion for continual increase of energy, applies not only to the case of axial symmetry but with perfect generality to all fields, with the exclusion of cases where the field passes through a zero value and there reverses its sign.

The considerations developed in former papers and pertaining to the condition where a particle starts from rest at the instant when the currents generating magnetic fields are zero has been extended to the case where the currents are finite when the particle starts to acquire energy. Criteria have been established which enable one, in certain cases, to calculate lower limits to the energy acquired. Interesting examples are afforded by a case where the currents flow in an infinite solenoid and where they flow as in an anchor ring winding. In both of these cases, the external magnetic field is extremely small, unless the rate of change of current is large, but, nevertheless, significant electromotive force can be generated in typical cases and cosmic-ray energies acquired.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

COSMIC-RAY OBSERVATIONS AT VERY HIGH ALTITUDES DURING PERIODS OF INTENSE SOLAR ACTIVITY †*

BY

M. A. POMERANTZ

A detailed study of the records of balloon flights which were at very high altitudes during periods of important solar disturbances has been conducted. Nine interesting events have been examined and subjected to extensive statistical analysis. Four of these indicated enhanced cosmic-ray intensity associated with outstanding activity on the sun as manifested either by the occurrence of Hα flares or

distinctive r.f. radiation events. In five instances, however, no effect is observed to accompany major chromospheric eruptions. The results cannot be accounted for solely on the basis of the expected impact zones for charged particles originating at the sun. Efforts are in progress to determine whether some recognizable fundamental differences between the two groups of flares exist.

† Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

* Abstract of a paper presented before the Congress on Cosmic Radiation, International Union of Pure and Applied Physics, Guanajuato, Mexico, September, 1955.

NUCLEAR RESONANCE FLUORESCENCE IN Ni^{60} *

BY

F. R. METZGER

Under favorable circumstances, the beta decay of Co^{60} and the subsequent emission of a 1.17 Mev gamma ray supply the recoiling Ni^{60} nucleus with enough momentum to restore the resonance condition for the 1.33 Mev radiation. In a solid source of Co^{60}, however, the recoiling Ni^{60} nuclei are slowed down by collisions before the 1.33 Mev gamma rays are emitted. The recoil due to the preceding radiation is, therefore, not effective, and resonance fluorescence cannot be observed.

In a gaseous source of reasonably small pressure, the probability for collisions is negligible when compared with the probability for the emission of the 1.33 Mev radiation. The 1.33 Mev gamma rays are, therefore, emitted while the Ni^{60} nuclei still move with the recoil velocities imparted to them by the beta decay and the emission of the 1.17 Mev radiation. One, therefore, expects to observe a resonance fluorescence effect with a gaseous source of Co^{60}, provided the lifetime of the 1.33 Mev transition is shorter than $\sim 10^{-10}$ seconds. According to Bay, Henri, and McLernon (1), the mean lives of both excited states of Ni^{60} are shorter than 10^{-11} second; a nuclear resonance fluorescence effect should, therefore, be observable if suitable precautions are taken to eliminate collisions in the Co^{60} source.

With a gaseous source of $Co^{60}Cl_2$, we have observed a large resonance fluorescence effect from the 1.33 Mev level in Ni^{60}. The preliminary data indicate that the half-life of this level is shorter than 10^{-12} second, but longer than 10^{-13} second.

The large uncertainty in $T_{\frac{1}{2}}$ is due to the use of a molecular vapor, for which the analysis of the recoil phenomena is rather involved. Experiments are underway to reduce the uncertainty in $T_{\frac{1}{2}}$ to a small fraction of its present size.

(1) Z. BAY, V. P. HENRI AND F. MCLERNON, *Phys. Rev.* Vol. 97, p. 561 (1955).

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

STUDIES IN IONIC CONDUCTION IN SOLIDS*

BY

W. E. DANFORTH AND J. F. MARSHALL

Information regarding the densities and mobilities of ions in solid materials is being sought by a method which appears not to have been used heretofore for the purpose. If a constant voltage is applied to a crystal which conducts by ions, or if a constant current is imposed, a polarization emf. appears. We are attempting to determine ion densities and mobilities by analysis of the rate of rise of the polarization. The mathematical problem is cumbersome, but some simplification is effected by using data obtained at the initial instant of application of voltage and current. The ion densities which are at present computed for thorium oxide by this method are somewhat too large and the variation of initial slope of the polarization with temperature does not appear to conform qualitatively with the theory.

* Supported by the U. S. Army, Office of Ordnance Research.

BOOK REVIEWS

PRODUCTION OF HEAVY WATER, edited by George M. Murphy. 394 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $5.25.

This book presents a detailed account of the development of processes for the separation of heavy water and the commercial production of heavy water undertaken by the Manhattan District in the years 1941–1946. The first part of the volume is a condensation of the excellent report by J. O. Maloney and the late H. S. Ray on the commercial production of heavy water by the Manhattan District. This report gives the detailed history of three of the processes investigated by the Manhattan District, with much information on the design and operation of commercial plants which will be of interest to other groups wishing to use the same processes. The processes described are the catalytic exchange between hydrogen and steam based on electrolytic hydrogen, the distillation of water, and the distillation of liquid hydrogen.

Part 2 of this volume contains a series of chapters describing the basic research work on these and other processes for heavy-water production which was conducted largely at Columbia University, under the direction of H. S. Urey, and at Princeton University, under the direction of H. S. Taylor.

The book makes no mention of the dual-temperature, hydrogen-sulfide exchange process, which was also investigated by the Manhattan District, and is now used by the USAEC for the primary concentration of heavy water.

The individual chapters of this text are informative and well written and have been conscientiously edited for the present publication. The principal shortcoming of the work is that it makes no mention of developments in heavy water subsequent to 1946.

MANSON BENEDICT

THE VIKING STORY, by Milton J. Rosen. 242 pages, 15 × 22 cm. New York, Harper & Brothers, 1955. Price, $3.75.

The significance of this book is heightened by the fact that the Department of Defense has recently signed a contract for the launching into space of a series of earth satellites or moons. This contract places the responsibility on the Glenn L. Martin Company of Baltimore whose principal experience in the field of rocketry has been the production and operation of the Viking, hero of Milton J. Rosen's story.

The Viking Story is a tale of man *vs.* machine with a wholly unexpected quality of suspense that makes it a far more gripping narrative for the non-technically minded than the title would suggest. Intense and dedicated personalities are involved in the build-up to the successful climax, an American-made rocket coasting silently, straight up, through the almost perfect vacuum of the outer atmosphere for minutes after the fierce thrust of the motor has died—up to a new world's record of 158 miles above the earth.

No group of men deserve more credit than the crews of experts in many specialties from both Martin and the Navy, particularly the Naval Research Laboratory, the "home port" of Milton Rosen who contributed to all phases and was in actual charge of the firings. This volume is so well written that they will not soon be forgotten, even with the current pace of developments on the rocket front.

In view of the underlying popular demand that the United States beat the Russians into the sky with at least a moderately conspicuous satellite, it is interesting to examine *The Viking Story* for evidence of our ability to do this. Under military security a whole new range of rocket techniques will be called on to get the baby moons into the sky. This much is certain: The highest officially announced speed for any large scale American rocket (6300 ft. per second, the speed of the brilliant Viking II which set the altitude record) is nowhere near good enough.

We have set ourselves a hard task and every reader of Rosen's book will believe it is a very hard task. This country has undertaken to stack up an assembly of three rockets each with a performance markedly superior to the best efforts of the original Viking project. The largest, or first stage, rocket will presumably have to be far larger than any with which Americans have direct

experience. If the Russians have operational rockets of this size they are not talking.

Not only will all three stages have to function in perfect sequence, but the average speed attained by each unit will have to be over 8000 ft. per minute. This is well within the potential of various fuel-motor combinations under intense development, but on the basis of the record here set down the pitfalls in the path of optimum realization are rather frightening. That strong hearts and heads are determined to meet the deadline set by the International Geophysical Year is encouraging, even stimulating. The magnitude of the undertaking can be judged from the stirring history of our best to date by Milton J. Rosen, who has done as much as any American to place mastery of space within our grasp. J. W. STREETER

LINEAR FEEDBACK ANALYSIS, by J. G. Thomason. 355 pages, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $8.50.

The term "feedback," as used in this book, means the electrical engineering concept of returning a portion of the output signal of an amplifying device to its input. Doing this has many useful consequences in electric circuits employed for the amplification of sound, control of machines, and computation.

The subject of "feedback" has occupied the minds of electrical and communications engineers since the earliest use of electric oscillators. A formal analysis of the effect, then called regeneration, was presented in 1932 by the famed Nyquist of Bell Laboratories. This regeneration was positive feedback, taking a portion of the output of an amplifying circuit and applying it to the input in such phase as to strengthen the effect. Negative feedback became popular just as its benefit in reducing distortion of audio amplifiers was appreciated. Finally, the feedback of a complex error signal was studied, and the term, servomechanism, was born. H. L. Hazen of M.I.T. published his "Theory of Servomechanisms" in this JOURNAL, in 1934.

The brief history above gives a background for the subject of feedback, lest anyone believe it new. Electrical control and communications engineers are of course familiar with the long list of texts that have developed the subject during the last two decades. Upon these solid and already rather complete foundations J. G. Thomason has prepared his book. In such a task it would indeed be difficult to know where to begin, for so much has already been done. Certain contributors have provided notable advances in the technique of analysis, as have Gardner and Barnes in their "Transients in Linear Systems." Published in 1942, this work was a thorough development of transform methods for solving control problems. Bode's "Network Analysis and Feedback Amplifier Design" (1945) is also a source that Thomason uses freely. He apparently overlooked MacColl's "Fundamental Theory of Servomechanisms" for no reference is made to it, even in the bibliography. There are also several recent books on control by Wm. Ahrendt, Robert Mayer, and others.

There is much that is good in Mr. Thomason's book, but the user should be cautioned that he must be either familiar with the subject from previous training or be prepared to do a large amount of supplemental reading. The brief glimpses of the analytical methods leave much to be learned before one can apply these tools readily. The worked-out problems are good but are limited in scope and do not include important mechanical components of systems.

The fields of application which employ feedback principles have become highly specialized. Work in these fields, particularly computation and control, is usually carried on by experienced engineers who started their specialization after a thorough grounding in general electronics. That is, it would be assumed that before taking up a specialized study such as feedback analysis, the student would have already studied steady state circuit analysis and the design of amplifying stages. Therefore, it seems superfluous to include chapters on these subjects as the author has done at the beginning of his book. Moreover, the manner in which they are treated has been necessarily brief and superficial owing to the confines of space. On the other hand, the author has done a tidy job in providing a text which should serve the instructor well in a brief course on feedback principles.

C. W. HARGENS

PROTECTIVE COATINGS FOR METALS, by R. M. Burns and W. W. Bradley. ACS Monograph No. 129. Second edition, 643 pages, illustrations, 16 × 24 cm. New York, Reinhold Publishing Corp., 1955. Price, $12.00.

This very factual monograph, though making no pretensions to being a manual, gives a rather detailed presentation of the theory, problems and methods used in protecting metal surfaces. Beginning with the "Principles of Corrosion and Errosion Control," it proceeds logically to surface preparations through the various types of coatings and methods of application. Included are descriptions of the test methods for evaluating the parameters attendant upon acceptable performance.

Whole chapters are devoted to discussions of the several metals used in protective coating. The history, nature of the protective action, performance under various environments and general values are presented in an interesting fashion. These coating materials are given: zinc, cadmium, nickel, chromium, copper, lead, aluminum, the noble and rare metals, and organic finishes. An additional chapter is devoted to a discussion of special purpose coatings including vitreous coatings, among others.

There are numerous tables, graphs and illustrations to interest the readers who seek data, and the chapter on surface preparation of the metals will benefit engineers concerned with treatments of metals generally. The methods described are those that are commonly used in surface preparation in industry. They include degreasing by means of solvent action and/or alkali action, ultrasonic cleaning, descaling by acid pickling or abrasion, flame cleaning, etc.

For the engineer or chemist who is concerned with the problem of corrosion, this book is an excellent guide and source of information. S. N. MUCHNICK

THE CHEMISTRY OF PETROLEUM HYDROCARBONS, edited by Benjamin T. Brooks, Cecil E. Boord, Stewart S. Kurtz and Louis Schmerling. Volume 2, 448 pages, diagrams, 16 × 24 cm. Price, $13.50. Volume 3, 690 pages, diagrams 16 × 24 cm. Price, $18.00. New York, Reinhold Publishing Corp., 1955.

Volume 2 of this three-volume treatise is similar to Volume 1 in that it deals with petroleum from the physical chemical aspect rather than from the organic chemistry viewpoint. Whereas in the first volume the editors presented the origin and composition of petroleum together with methods for separating, and the physical properties of, the various hydrocarbon constituents, the second volume deals with the mechanisms and variables associated with thermal and catalytic cracking. Volume 3 is devoted to the organic chemistry of petroleum hydrocarbons, and it is presented from the standpoint of reactions, reaction mechanisms, and derivatives. Obviously the chemistry of the derivatives is not included since they cover just about the entire field of organic chemistry. However in some cases detailed discussions of reactions are given, but are limited only to those areas where the information helps to shed more light on the basic structure of petroleum.

More specifically, Volume 2 presents information on the following subjects:

(*a*) Mechanisms and conditions for, and results from, thermal cracking of hydrocarbons together with the chemical compositions of the end products,
(*b*) Reaction rates, heats of formation, and the effect of the variables (temperature, pressure, contact time, catalyst type and activity, catalyst/oil ratio, feed stock type, etc.) in catalytic cracking,
(*c*) Methods of upgrading low-grade stocks, and
(*d*) Theory, mechanics, and mechanisms of the oxidation of hydrocarbons.

One of the most interesting sections of this volume, in the opinion of the reviewer, was the chapter on upgrading low grade stocks by platforming, hydroforming, and aromatization. Platforming is a catalytic reforming process made up of a number of chemical reactions, but it is free of side reactions thus eliminating non-productive sections. Hydroforming is the interaction of hydrocarbons with hydrogen resulting in a cleavage of carbon to carbon bonds.

Aromatization is either the dehydrocyclization of paraffins to aromatics or the dehydrogenation of naphthenes to aromatic hydrocarbons.

The contents of Volume 3 can be classified under the following headings:

(*a*) Isomerization of saturated and unsaturated hydrocarbons,
(*b*) Halogenation and nitration of, and complex formation with, paraffins and cycloparaffins,
(*c*) Olefin polymerization,
(*d*) Condensation and substitution reactions with olefins and aromatics,
(*e*) Sulfonation and vitration of aromatic hydrocarbons,
(*f*) Hydrogenation of cracked oils, catalytic naphtha, catalytic cycle stock, and shale oil, and catalytic hydrogenation of hydrocarbons,
(*g*) Chemistry of natural and synthetic rubbers,
(*h*) The formation of polymer gasoline, and
(*i*) The oxo-reaction (formation of aldehydes from the reaction of carbon monoxide, hydrogen, and an olefin).

The most interesting section in this volume, from the standpoint of the commercial possibilities involved, is the chapter on polymer gasoline. The formation of polymer gasoline is a process by which normally gaseous olefins are polymerized, hydrogenated, and alkylated to form gasolines for aviation and automible use.

It is very difficult for the writer to review these volumes critically since there is so much to praise and so very little to criticize. *The Chemistry of Petroleum Hydrocarbons* most definitely fills the need in a field that has already outgrown its expected bounds. The editors have very skillfully managed to sieve the plethora of available information on this subject and come out with a neat package containing the facts of most importance to the workers in the field. Even though each of the volumes in the series can stand by itself, one must recommend all three since this treatise obviously will soon become a reference work or handbook for the field.

D. H. RUSSELL

SCIENTIFIC METHOD IN PSYCHOLOGY, by Clarence W. Brown and Edwin E. Ghiselli. 368 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $6.00.

Since psychology is a fairly recent inclusion in the roster of scientific disciplines, considerable time and effort have been spent by psychologists in either presenting arguments to strengthen psychology's position as an accepted scientific discipline or else in suggesting rituals for thinking, which if followed by their less sophisticated colleagues, will result in psychological research of scientific validity. This book takes the second of these two courses and suggests rituals and techniques, which if followed, should result in scientifically acceptable research. This is a useful contribution to the education of young scientists for it enables them to fill in the detail in the scientific picture sketched by the leaders in the scientific field. Valuable as training in mechanics and technique is, and what chemist would deny the value of learning to use equipment and to design experiments, scientific progress requires the creative intuition of leaders to boldly sketch the outline of the expanding and changing picture later to be filled in and detailed by their less gifted followers. Unfortunately, a text listing the procedures to be followed to insure scientific creativity has yet to be written.

The authors have discussed several so-called postulates of the scientific method, and it is hard to agree with certain of their choices. For example, the postulate of determinism is a weak foundation for any modern science. A major advancement took place in physics when statistical relations between events supplanted the classical notions of deterministic causality. Another postulate is entitled the "Concept of immutable laws." With regard to this postulate it is stated in the text on page 21 that: "For our purposes the important point is that natural phenomena, in the main, change slowly and consequently the laws governing their expression need to be changed only infrequently." This statement is absurd since it is our *descriptions* of nature that change, and not nature herself. Our descriptions of nature need not be slowly varying, and, in

fact, rarely are. Innovations generally involve radical new assumptions; such as Planck's quantum hypothesis, for example. The last postulate with which I would quarrel is entitled the "Reliability of reasoning." The authors do not make the point that our syllogistic logic, or in fact all verbal logic is derivative, in a sense, from the structure of the language used. The limits and pitfalls of verbal reasoning are of special importance to psychologists who, as a group, rarely use symbolic logic systems.

In general this text is valuable reading. There are many fine discussions of the variables which must be controlled in a psychological experiment. It would do engineers a world of good were they to read these sections and thus gain some sophistication in the design of multivariable experiments. Statistical inference is treated on mainly a verbal level, but this is no shortcoming, since many adequate statistics texts are available. In summary, the technical aspects of the scientific method have been well handled, but the more philosophic basis for modern science suffers by comparison.

EZRA S. KRENDEL

HANDBUCH DER MIKROCHEMISCHEN METHODEN, BAND II, edited by F. Hecht and M. K. Zacherl. 423 pages, diagrams, 18 × 25 cm. Wien, Springer-Verlag, 1955. Price, $19.30 (20% discount when whole encyclopedia is purchased).

There are five volumes in the complete *Handbuch*. Volume I contained the following contributions: Preparative Micro Methods in Organic Chemistry; Microscopical Methods; Biochemical Methods Including Medical Procedures; Microchemical Methods in the Food Industry. Volumes 3 to 5 will present Inorganic Analytical Methods, Organic Analytical Methods, Polarographic Methods and Micro Methods for the Determination of Constants in Physical Chemistry. The present Volume 2 contains three contributions which will be discussed separately.

1. Application of Radioactivity in Microchemistry, by E. Broda and T. Schönfeld.

Due to the high sensitivity with which radioactive substances can be detected by means of their radiation, the radiochemical analysis is extremely sensitive. Therefore it is best used in microchemistry. After an historical introduction, two separate ways of applying marked atoms are pointed out, namely the analytical and the kinetical methods. While the analytical methods are much more sensitive than other methods, they do not do anything more that could not eventually be achieved by conventional means. The kinetic applications, however, produce results which cannot be obtained by any other method known today. A classical example of the latter method is Hevesy's investigation of the exchange of lead between the metal electrode and the lead ions in solution. This meant that it was possible for the first time to study the exchange, migration or transport of identical atoms.

In the second chapter the fundamentals of radioactivity are discussed. This is followed by a third chapter on the chemical behavior of radioactive substances. Then all the different applications of radioactivity to the chemical analysis are described such as the Indicator Analysis, Analysis with Radioactive Reagents, Method of Isotope Dilution, Activation Analysis and the Analysis by Radiation Absorption and Scattering on the Nucleus. Special emphasis is given to the outline of the experimental limits. The use of radioactive indicators or the activation analysis often raises the sensitivity by several decades as compared with other methods. Analyses which yielded only inaccurate results due to incomplete separations of the components could be essentially improved by the application of the method of isotope dilution. In many cases the radiochemical methods aid in the development and checking of other analytical methods. An important advantage of radiochemical analysis is the ease with which it can be applied and its non-destructiveness. There is also a discussion of the chemical behavior of minute amounts of substance and the resulting procedures for the separation and purification of radioactive elements. Here the methods of ion exchange, selective solvents and complex formation which just recently became of high importance, are treated. Finally separate paragraphs are devoted to the work with individual radio-

active elements and to the biological effect of radioactive radiation and its health hazard.

2. Measurement of Radioactive Radiation in Microchemistry, by T. Bernert, B. Karlik, and K. Lintner.

After a brief presentation of the theoretical background, the Ionization Chamber, the Counters, and the more sensitive Scintillation-, Crystal-, and Spark-Counters are discussed in separate chapters. The authors do not expect the microchemist to be familiar with the different procedures used in measuring radioactive radiation. They discuss thoroughly the different methods used for measuring radioactivity in order to aid in the selection of the proper apparatus to be used for a specific task. Methods which are especially useful in micro chemistry are emphasized by practical examples. This will help the micro chemist to interpret his measurements and to avoid sources of error.

3. Photographic Methods in the Radiochemistry, by H. Lauda.

Today photographic emulsions are available which permit the detection of alpha and beta radiators as well as such elements which produce suited nuclear reactions. Thereby the detection can be of a qualitative as well as quantitative nature. Very appealing is the fact that this method requires a negligible amount of apparatus. This permits the method to be used by laboratories which are otherwise not equipped to measure radioactivity. Due to the integrating effect of the photographic emulsion, this method is particularly suited for very weak activities. Besides this, radiation centers can be localized much better than with other methods. This is important for the detection of radioactive isotopes in minerals and in microtuned sections. As in the previous contributions, the physical concepts are discussed first. Then practical advice is given for the selection of the right emulsions and on the development and evaluation. Sources of errors are discussed. Finally the different methods and applications are treated.

Extensive literature references are given at the end of each chapter throughout the book. Author and subject indexes conclude the volume. The authors are to be congratulated for making this book a most valuable guide through this extremely interesting subject.

KARL SITTEL

BOOK NOTES

THE FORESEEABLE FUTURE, by Sir George Thomson. 166 pages, 14 × 22 cm. New York, Cambridge University Press, 1955. Price, $2.50.

The author, son of Sir J. J. Thomson, is a scientist in his own right. In this compact, but provocative book, he analyzes several broad fields of technology to predict what will happen to them in the next hundred years. He covers these subjects: energy and power (what will happen when oil and coal supplies are exhausted); materials (sailing-ship, transparent buildings of enormous strength); transportation and communication (self-driven vehicles and "conventions" where those in attendance are seated at their own desks); meteorology (weather prediction by radiosonde); food (manufactured instead of grown); biology (monkeys may be useful work animals). Chapters on "Some Social Consequences" and "Thought, Artificial and Natural" complete this fascinating look at our technological future.

TECHNICAL PUBLICATIONS, by C. Baker. 302 pages, diagrams, 14 × 21 cm. New York, John Wiley & Sons, Inc., 1955. Price, $6.00.

In this "paper" age of reports and more reports, the author of this volume feels that the answer is not fewer, but better, reports. The need for technical literature is obvious; this book offers help to the authors of technical literature, toward making their writings more concise, more interesting, and more apt to be read. After describing several kinds of technical publicity and discussing ways to meet the user's needs, the book offers definite and valuable suggestions on the use of words and the value of illus-

trations. An informative chapter on the various methods of reproduction should be of interest to reproduction department heads. An equally detailed chapter on copy preparation, proof reading and final production should be read by all authors. The book, beautifully printed and illustrated, could be read with profit by all reporters of scientific subjects, by all authors of technical papers and reports.

INTRODUCTION TO CHEMICAL ENGINEERING, by Walter L. Badger and Julius T. Banchero. 753 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $9.50.

Designed as an introduction to unit operations, this text aims to give the student a solid foundation in chemical engineering. Both theory and engineering applications are covered, in a logical sequence. Prerequisites for the course are a working knowledge of chemistry, a one-year college course in physics, calculus, the fundamentals of thermodynamics, and an elementary knowledge of machine parts and construction. In the illustrations, actual detailed construction is emphasized, rather than diagrammatic sketches.

HANDBOOK OF HYDROCARBONS, by S. W. Ferris. 324 pages, 16 × 24 cm. New York, Academic Press, Inc., 1955. Price, $8.50.

Composed of four tables, this handbook should be valuable to all those working with hydrocarbons. Table A lists hydrocarbons in the order of their known boiling points. Table B arranges hydrocarbons in groups of the same empirical formula and the same type (alkanes, alkenes, alkynes, cyclanes, cyclenes, cyclynes, aromatics). Table C lists alternate names alphabetically, cross-referenced to Table B, for those whose terminology differs from that of the compiler. Table D is an alphabetical listing of the numbered formulas of various hydrocarbons.

PUBLICATIONS RECEIVED

ELECTRONIC AND RADIO ENGINEERING, by Frederick E. Terman. Fourth edition, 1078 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $12.50.

PRACTICAL MATHEMATICS REFRESHER, by William D. Reeve & Clarence E. Tuites. 376 pages, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $3.25.

RADIO OPERATING QUESTIONS AND ANSWERS, by J. L. Hornung and A. A. McKenzie. Twelfth edition, 571 pages, diagrams, 14 × 21 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $4.50.

HAWLEY'S TECHNICAL SPELLER, compiled by Gessner G. Hawley and Alice W. Hawley. 146 pages, 13 × 19 cm. New York, Reinhold Publishing Corp., 1955. Price, $2.95.

UNITED STATES ARMY IN WORLD WAR II. THE WAR IN THE PACIFIC. SEIZURE OF THE GILBERTS AND MARSHALLS, by Philip A. Crowl and Edmund G. Love. 414 pages. illustrations, 17 × 25 cm. Washington, D. C., Department of the Army, 1955. Price, $5.75.

SOIL AND WATER CONSERVATION ENGINEERING, by Richard E. Frevert, Glenn O. Schwab, Talcott W. Edminster, and Kenneth K. Barnes. 479 pages, diagrams, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1955. Price, $8.00.

INDUSTRIAL FURNACES, VOLUME II, by W. Trinks. Third edition, 358 pages, illustrations, diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1955. Price, $10.00.

INTRODUCTORY NUCLEAR PHYSICS, by David Halliday. Second edition, 493 pages, diagrams, 14 × 21 cm. New York, John Wiley & Sons, Inc., 1955. Price, $7.50.

DIMENSIONAL MOTION TIMES. DEVELOPMENT AND APPLICATION, by H. C. Geppinger. 100 pages, diagrams, 22 × 28 cm. New York, John Wiley & Sons, Inc., 1955. Price, $4.00 (paper).

THE EXPRESSION OF THE EMOTIONS IN MAN AND ANIMALS, by Charles Darwin, with a preface by Margaret Mead. New edition, 372 pages, illustrations, diagrams, 13 × 21 cm. New York, Philosophical Library, 1955. Price, $6.00.

CELESTIAL NAVIGATION FOR YACHTSMEN, by Mary Blewitt. 64 pages, diagrams, 12 × 18 cm. New York, Philosophical Library, 1955. Price, $2.75.

CURRENT TOPICS

Magnetic Refrigerator.—A new-type refrigerator that will maintain lower temperatures than any previous apparatus has been developed at Arthur D. Little, Inc., Cambridge, Mass. The temperature produced in this machine—approximately 500 deg. colder than those of the refrigerator in your kitchen—comes to within a fraction of a degree of the coldest temperature that scientists believe can ever exist. The interior of the refrigerator would be even colder than the remote depths of outer space.

Spokesmen for the company explain that the design represents a major departure from ordinary refrigerating systems. It is based on a cyclic principle of magnetic cooling originated by Drs. John G. Daunt and Clifford V. Heer of the Ohio State University.

There are no moving parts or flowing fluids in this cooling system. It uses, instead, a plastic capsule three inches long, containing a special chemical salt as the refrigerant. Operation of the refrigerator is controlled entirely by external magnetic fields.

The principle of magnetic cooling —the fact that certain materials will warm up when magnetized and cool when demagnetized—has been used for several years in a few cryogenic (low temperature) laboratories for achieving extremely low temperatures in the range of Absolute Zero (−459.6° F.). This is the first apparatus, however, that has been able both to produce these extreme low temperatures and to maintain them for long periods of time. All previous equipment would immediately begin to warm up as soon as the low temperatures had been reached.

The ADL Magnetic Refrigerator is believed to represent the first commercial application of the phenomenon called "superconductivity." This is a change that certain metals undergo at very low temperatures in which they lose all resistance to an electric current. Hence the term, "superconductivity." At the same time, metals in the superconducting state act essentially as thermal insulators but conduct heat readily when not showing the superconducting effect. It is this thermal phenomenon of superconductors that is employed in the new ADL machine.

Company spokesmen said that the ADL Magnetic Refrigerator will enable scientists to carry out many new experiments aimed at getting a better understanding of the basic laws of matter. They explained, for example, that many of the more subtle changes going on in atoms and molecules are difficult to measure at ordinary temperatures because these tiny bits of matter are constantly darting and dancing about. But, at extremely low temperatures near Absolute Zero, atoms and molecules become quiet and can be more easily studied.

The Magnetic Refrigerator will complement the work of another product of ADL's extensive experience with low temperature equipment—the ADL Collins Helium Cryostat, a machine for making liquid helium. The Cryostat is now used in more than 75 per cent of the nation's low-temperature laboratories. The magnetic refrigerator is now available as a companion to the Cryostat for exploring the mysteries of the low temperature world.

Compact, Low-Priced Graphic Recorder.—A portable, modestly-priced graphic recorder, capable of widespread applications in the recording of data, has been introduced into the Varian line of equipment, according to a recent announcement by Dr. Russell H. Varian, president of Varian Associates, Palo Alto, Calif. The lightweight, compact Model G-10 Graphic Recorder has dimensions of 10 in. × 7⅛ in. × 8 in. It may be used directly as a recording millivoltmeter or, with appropriate transducers, as a means for recording pressure, light intensity, temperature and many other physical quantities. The recorder is designed to conform to rigid electrical and mechanical specifications.

According to the manufacturer, the new, 15-lb. Model G-10 is the first instrument of its kind which combines practical low-cost with the operating characteristics necessary for dependable recording of scientific phenomena. The instrument is of the self-balancing potentiometer type, and features a standard full-scale response time of 2.5 seconds and a standard sensitivity of 100 millivolts full-scale. Accuracy is 1 per cent and maximum allowable signal source resistance is 0.5 megohms.

Paper Tubular Capacitors.—Cornell-Dubilier (South Plainfield, N. J.) announces immediate availability of its new *Royal Cub* paper-dielectric capacitor designed to combine advantageous new electrical features for high temperature and high stability operation with exceptional mechanical toughness and long-life characteristics achieved by the use of *Polykane*—a solid thermosetting compound developed exclusively by C-D engineers.

Polykane enables the *Royal Cub* to withstand rough handling, severe vibration and shock, climatic extremes of heat and cold, moisture and humidity, and soldering iron heat without damage to the case material, moisture seal, wire lead connections, or over-all electrical performance.

The new *Royal Cub* was created specifically to meet the demand of general-purpose, severe-service applications where high-temperature operation, high stability, and smallest possible sizes are required at economical cost.

The *Polykane*-impregnated capacitor sections of C-D's *Royal Cub* operates over a temperature range of −55° C. to · +100° C. at full-rated voltage. Average capacitance-temperature variation is only 5 per cent from the 25° C. value. Insulation resistance at 25° C. exceeds 4,000 megohms-mfd., with power factor less than 1 per cent.

Royal Cub is available in 100, 200, 400, 600, and 1,000 volts D.C. working, and capacitances from .001 to 1.0 mfd., depending on voltage.

Alternator for Guided Missiles and Aircraft.—A new 400-cycle, 12,000 rpm. alternator for application on guided missiles and aircraft has been announced by the General Electric Company's Specialty Component Motor Department. Designed to meet extreme environmental requirements for periods of short duration, the alternator can be driven by a wide variety of prime movers, including d.c. motors, jet air drives and turbines, using either solid or liquid propellants. Although the unit weighs less than fifteen pounds, a further weight reduction can be made by substituting an AND 10261-type mounting pad for the normal AND 20001 pad.

Capable of continuous operation, the alternator contains a stabilized alnico permanent magnet field and can be rated as high as 2000 volt-amperes at unity power factor. It is a three-phase, 115 volt, wye-connected unit. Flexible both in construction and application, the alternator can be manufactured to produce more output when required.

Air Dryer.—A new air dryer, originally developed for use with a precision infrared spectrophotometer, is now available from Beckman Instruments, Inc. Fully automatic, the air dryer delivers air with less than 1 per cent relative humidity. It can be used with infrared spectrophotometers; in low temperature studies to prevent moisture fogging glassware, windows or mirrors; in balance enclosures or wherever reactions must be carried on under moisture-free conditions.

A 24-hr. instrument, the air dryer employs activated alumina as drying agent. The dryer will deliver 100 cu. ft. of dry air per hour all day long, then regenerate automatically at any selected time. During regeneration, the main blower turns off, the alumina is heated to 400° C. and the moisture-laden air is discharged to atmosphere. When regeneration is complete, the operating cycle begins again automatically.

Electronic Gauge Used by Blind.—The magic of electronics is allowing blind people to carry out successfully the precision testing of close tolerance production parts at Burroughs Corporation's main plant in Detroit. Using an ultra-sensitive electronic sound gauge, developed by Burroughs manufacturing engineers, blind employees will be able to test quickly and accurately the thousands of precision parts the corporation produces for use in its business machines and equipment, engineers said.

The sound gauge, under test by Burroughs for some time, was demonstrated before production experts by Charles D. Sullivan, employment specialist for the Michigan Social Welfare Commission and Nick Sotnick. Both men are sightless. Each learned to operate the gauge with approximately five minutes of instruction.

"This is one more important step in behalf of the blind," Sullivan declared following the demonstration. "It has tremendous possibilities."

The gauge, about the size of a telephone, is connected by cable to an amplifier and measures accurately to 0.0002 in. Production parts are inserted into a measuring anvil. A thickness reading is taken electronically. The reading is indicated on a dial and at the same time is transformed into a sound tone, as well as a visual light signal.

The blind operator, wearing a head phone similar to that of a hearing aid, hears a low pitched tone for parts that are under the proper thickness and a high pitched tone for those parts over the required thickness. Parts meeting the requirements produce no tone at all.

Engineers point out the flexibility of the device indicates other uses can be easily adapted. It is comparatively inexpensive to produce and virtually foolproof in operation.

Sun Supplies Power for Telephone Line.—On October 4, for the first time, the sun—ultimate source of all the power which man has at his disposal—began furnishing power directly to a telephone line. At 10 A.M., Bell engineers switched solar power into a new type of rural telephone system using the Bell Solar Battery, an invention of Bell Telephone Laboratories announced last year. Use of solar power is a part of experiments being conducted near Americus, Ga., 135 miles south of Atlanta, to develop more and better rural telephone service.

George L. Mathews, a cotton and peanut farmer, made the first sun-powered telephone call and remarked that it sounded "just fine."

The Bell Solar Battery is the first successful device to convert the sun's

energy directly and efficiently into substantial amounts of electricity. It is at least fifteen times more efficient than the best previous solar energy converters.

Excess current from the solar unit not needed for immediate telephone use feeds into a storage battery which provides power at night and over periods of bad weather.

The solar battery has no moving parts or corrosive chemicals and therefore should last indefinitely. Even in poor light, it will continue to charge the storage battery but at lower power.

The telephone system, under trial at Americus in co-operation with Southern Bell Telephone Co., uses transistors instead of traditional vacuum tubes. The transistor, invented at Bell Laboratories and announced seven years ago, requires only small amounts of power.

The new system uses the "carrier" principle which allows several conversations to be sent simultaneously over a single pair of wires. Since each conversation is sent at a different frequency, they do not interfere with each other. Multifrequency transmission has been used for years—with vacuum tubes—on longer distance calls. The system on trial at Americus, however, operates economically over shorter distances such as those on rural telephone lines.

Since the solar battery is still very new, long-range predictions are difficult to make. It might be used economically for communication uses where commercial power is unavailable and where small amounts of power are sufficient. Bell hopes to find out from this trial whether or not solar power can be used for rural telephone equipment.

The solar battery being used for the Americus trial is encased in an aluminum housing less than a yard square. It contains 432 silicon cells, cushioned in oil and covered by glass. Silicon cells can convert as much as 11 per cent of the energy they receive from the sun directly into electrical power—a performance comparable to that of the best gasoline and steam engines.

Specially-prepared silicon used for the cells is obtained originally from common sand, one of the world's most abundant materials. Silicon is a semiconductor, with properties similar to germanium, the material used in most transistors.

The Bell Solar Battery uses disks of wafer-thin silicon about the size of quarters. These cells are extremely sensitive to light and can be electrically linked together to deliver power at the rate of 100 watts per square yard of effective surface.

A "diffusion" technique developed at Bell Laboratories is used for producing these silicon cells. A thin slice of very pure silicon is treated under gas at high temperatures. This permits the controlled introduction of certain impurities into the atomic structure at the surface of the silicon. This is done at a precise rate to reach a depth of less than one ten-thousandth of an inch. The boundary created in the cell between the two different regions of electrical conductivity is referred to as a "p-n junction," and is the heart of the device.

Automation in the Accounting Department.—A development model of the Burroughs "Sensitronic," which brings a high degree of automation to bank and general posting, was shown recently for the first time at the American Bankers Association convention in Chicago.

The device is an additional component in a series of machines for automatic bank check handling and bookkeeping now in various stages of

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development and testing by Burroughs Corporation of Detroit. Burroughs and a subsidiary, The Todd Company of Rochester, N. Y., exhibited three units designed for automatic check handling—an imprinter, a coder and a sorter—in their exhibits at the Conrad Hilton Hotel. Development of these machines was disclosed several months ago in a joint announcement made by Burroughs, Todd and Addressograph-Multigraph Corporation of Cleveland.

The Sensitronic combines electromechanical and electronic principles to perform several posting operations without assistance from the operator, thereby eliminating the possibility of human error in those particular operations.

A magnetic code stripe on the back of the form is utilized to give instructions to the machine. When the operator drops the form into the carriage, the machine adjusts the sheet so that there is proper vertical and horizontal alignment with the last previously printed item. This assures neater, easier to read statements than have been possible before.

At the same time, the machine acts on instructions from the stripe to print the old balance. When entries are made by the operator, those items also are printed on the sheet. The machine automatically computes and prints the new balance and also records it magnetically on the stripe for future posting. After the operation is completed, the machine automatically ejects the form.

As an added guard against error, the account number also can be coded on the stripe. At the time the posting is to be made, the operator can index into the machine the last few digits of the account number. The machine will compare this number with the account number on the stripe. If the numbers match, the Sensitronic will carry out the posting operations. If the numbers do not match, the machine locks automatically, thus preventing error in posting to the wrong account.

Another device, employing electronic principles, the "Bank-o-Matic," also was announced at the ABA show. The "Bank-o-Matic" presents a new principle of commercial bookkeeping, utilizing a punched paper tape as input of account numbers, activity and balances. Operating with checks and deposits coded with invisible signals, account activity and balances are updated on output tape, a complete daily transcript of all accounts is prepared and an automatic trial balance obtained. In addition, the "Bank-o-Matic" prepares all statements automatically on cycle dates or at month-end.

It is expected that these two machines, at two different levels of automation for banking operations, will provide bankers an opportunity to select the best machines for their needs. Within the next few months, field tests will be started on these devices in an eastern bank.

Capt. Cook's Cloaks Get a Cleaning.—Priceless cloaks made from the tiny feathers of extinct Hawaiian birds, which were presented to Captain Cook before his death in Hawaii, recently got their first cleaning in 176 years. One of the cloaks is said to have taken a century to make, so the cleaning process was necessarily a delicate operation. As a cleaning compound, experts selected a mixture of oil-based synthetic detergents and plain water. The gentle-acting suds brought out the original brilliant reds and yellows of the cloaks.

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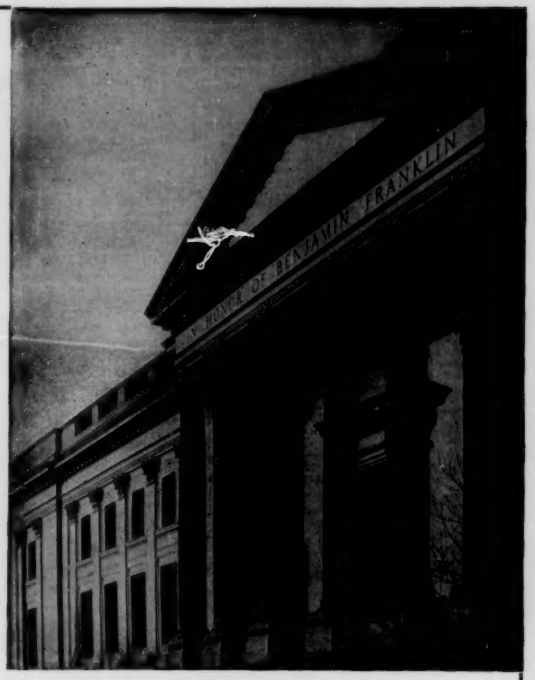

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